ENIGMA III

User Manual

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EDITION	REVISION	DATE	Modification Object
1	0	22/11/2007	First Edition by mt
1	1	20/06/2008	vk - Added DualPolMode, AFCSettings, thresholdFlagsTable, ZeroFilter, gasAttenuation - Added: noisesample, sampleburst, setafcmode - Ray data format
1	2	06/10/2008	mt – Minor text revisions – Added trigger, coho, sector blanking and extended dynamic range parameter
1	3	09/10/2008	mt New error code
1	4	19/12/2008	ss SDP Status in ray format has – amount of free memory instead of memory usage

1 Introduction

History of GAMIC SDP Processors

1995	GSP01	*PC Card for non Doppler Low-Cost Applications*
1996	GSP02	*Stand alone Doppler Signal Processor*
1997	ENIGMA I	*First generation of high performance video baseband Doppler Processor. Up to 2 MAIN boards (3 DSP's) and 3 Expansion boards (8 DSP's) each*
1998	ENIGMA II	*High performance Digital IF Doppler Signal Processor Receiver. Up to 2 MAIN boards (6 DSP's) and 3 Expansion boards (8 DSP's) each.*
2003	ENIGMA III	*High Performance FPGA / Linux host based dual polarization IF Doppler Signal Receiver. Signal processor algorithm run on a LINUX based host computer.*

The ENIGMA III Signal Processor consists of two main modules. The IF-Digitizer (IFD) and the Signal Processor host computer. The host computer is basically a Linux based standard industrial PC. ENIGMA III performs two main tasks:

- Digital Receiver Functions to obtain I, Q and Burst Pulse statistics. This processing is done on the IFD and includes matched-filtering and extraction of dynamic "I" and "Q" values. In addition, burst pulse is analyzed with respect to frequency, phase and amplitude to provide digital phase locking, AFC and advanced processing and control features not present in traditional radar's.
- Weather Information extraction to obtain Intensity, Velocity and spectral width and dual polarization moments like ZDR, LDR, KDP, PHIDP and RHOHV. This operation include Doppler and Intensity processing to extract the calibrated reflectivity, the mean velocity and spectrum width. Clutter filtering by Doppler filtering in the time- or frequency- domain, thresholding and velocity unfolding by dual PRF.

The IF Digitizer Module is housed in a sealed box. The main purpose is to digitize the analog IF signals with a minimum of additional computational effort. The fiber optic link ensures the galvanic isolation of the IF Digitizer Module from the rest of the digital components, thus avoiding additional ground loops and other stray effects. Note, that the "Uplink" serial coaxial cable is isolated as well from the IF Digitizer Module. Due to this technique, distances up to 100 meters between the IF Digitizer module and the signalprocessor can be realized.

2 Algorithms

2.1 Thresholding

As the radar signal is contaminated with noise it is important to apply thresholding to the radar data. Thresholding means that bins that pass one or the combination of several tests are discarded and flagged as invalid. A combination of the following thresholds can be applied to all physical moments. The combination of the flags is stored in a binary bit mask.

Parameter: **thresholdFlagsTable**

Remark: *The value for the threshold flags can be calculated with the Tool EnigmaThresholdFlagCalculator*

Threshold combination	**Value**
All Pass	FFFF
All Fail	0000
SQI	3333
SQI | NOISE	0033
SQI | CCOR	1111
SQI & CCOR	7777
SQI | NOISE | CCOR	0011
CCOR	5555
CCOR | NOISE	0055
NOISE	00FF
RHOHV	0F0F
RHOHV | SQI	0303
RHOHV & SQI	3F3F
RHOHV | NOISE	000F

Table 1: Useful threshold flag combinations

2.1.1 Noise Power threshold

The Noise Power threshold [dB] is related to the noise floor measured through noise sampling and is applied to reflectivity data. Typically, the noise threshold is 1 dB above the noise floor.

Parameter: **NOISEThreshold**

2.1.2 CCOR threshold

The clutter power threshold [dB] is compared to the clutter power, obtained from the 4. order Chebyshev IIR high pass filter or the filtered result from the frequency domain filtering. Reflectivity data and/or radial velocity and/or spectral width data can be thresholded, when the calculated clutter power exceeds the clutter threshold limit.

Parameter: **CCORThreshold**

2.1.3 SQI threshold

The Signal quality threshold (SQI) is compared to the signal quality, resulting from autocorrelation processing. A signal quality value of 0 represents only noise, whereas a value of 1 represents a perfect tone (sine wave). This threshold is absolute for thresholding of Doppler moments (radial velocity and spectral width). Typically values for thresholding are 0.4..0.5, depending on receiver input S/N ratio.

Parameter: **SQIThreshold**

2.1.4 RHOHV Threshold

In SIDPOL configuration the RhoHV moment can be used for thresholding. RhoHV is close to 1 for spherical targets (water droplets) and quickly falls to lower values for other targets. A good starting value would be 0.7-0.8

Parameter: **RHOHVThreshold**

2.1.5 PhiDP SNR Threshold

In SIDPOL configuration the PhiDP and the related KDP moment can be thresholded with SNR. If the SNR of the signal is lower than the specified threshold the PhiDP and KDP moments will be thresholded. Set threshold to 0 to disable this thresholding algorithm.

Parameter: **PhidpSNR**

2.1.6 Adjusting reflectivity thresholds

Uncorrected reflectivity data (UZ) is not corrected for clutter. In order to compare the influence of threshold adjustments for corrected reflectivity data (CZ), open two A-Scopes or PPI's. One for uncorrected reflectivity and one for corrected reflectivity.

2.1.6.1 NOISE Threshold Parameter

This threshold [dB] rejects corrected reflectivity data, which is n dB above the noise floor. The noise floor was obtained from noise sampling.

In the Extended parameter dialog in FrogRT

- Set the noise threshold (Typically the threshold is set to 0.5..2 dB)
- Select NOISE for CZ threshold flags
- Click on Apply

Observe the two displays for UZ and CZ data. The CZ data should present a „clean“ picture without noise. Fine-tune the noise threshold setting.

2.1.6.2 Clutter threshold Parameter

Two parameters in the extended SDP settings are related to clutter processing and thresholding:

2.1.6.2.1 CCOR Threshold:

The CCOR threshold is selectable from 0 dB .. -90 dB. The clutter power is obtained from the 4th.order clutter filter or from the frequency domain processing. If the clutter power is less than the CCOR threshold, reflectivity data may be thresholded (=rejected), if the appropriate CZ threshold flag CCOR is enabled (CCOR is always negative as it is the Clutter Correction value in dB).

2.1.6.2.2 IQ clutter filter

The 4th. order high pass clutter filter can be configured to have different cutoff frequencies. All filters have a stop band attenuation of 40 dB (or 50 dB depending on the selected filter set).

Allpass filter means no filtering. It does not remove any clutter. Filter IQ1 has the lowest cutoff frequency, filter IQ7 has the highest cutoff frequency. Filter IQ1 is the „smoothest“ filter type, which will probably reject little clutter, whereas filter type IQ7 will remove most of the clutter. Unfortunately, weather and clutter spectra overlap, so it is important to select a clutter filter, which offers a good compromise. From experience, IQ2..IQ4 should be selected for a first step.

When using the frequency domain filtering (FFT and DFT mode) Interpolation or Dual Slope Interpolation should be used. These filters do not affect weather targets overlapped by clutter

- Set CCOR threshold to –30 dB.
- Select Clutter Micro Suppression Threshold (30-40dB) if you are using range sampling
- Select IQ clutter filter to IQ3.
- Select NOISE | CCOR for CZ threshold flags.
- Click on Apply in the extended SDP settings.

With this parameter settings, clutter will be thresholded (= rejected), when the calculated clutter power is less than the CCOR threshold level otherwise the measured clutter power is subtracted from the echo. If you can identify a strong clutter target in the closer area of the radar, observe the difference in the uncorrected and corrected reflectivity A-Scope.

The results when using **Pulse Pair Processing** (**PPP**) or one of the frequency domain processing modes (**FFT** or **DFT**)will be different. The main difference is that the time domain filtering used by PPP is not adaptive. It will always subtract the power measured at zero velocity. Regardless if there is clutter present. As an side effect weather at zero (radial-) velocity will also be attenuated. The clutter filter used by the frequency domain processing modes are adaptive. The filter will adapt to the spectrum (both in attenuation and width).

Remark: *As the frequency domain filters (**Interpolation** and **Dual Slope Interpolation**) adapt to the signal it is not necessary to keep them as small as possible (As would be necessary with the classical time domain filtering). IQ5 is a good starting value for frequency domain processing.*

Remark: *The clutter filter for Pulse Pair Processing should be as small as possible and should be switched off for higher (clutter free) elevations. A good value for time domain filtering would be IQ3.*

Parameter: **ClutterFilter and MaxFilterRange**

2.1.6.3 Clutter filtering examples

Consider the following example. The spectrum shows the combination of a strong clutter target and weather.

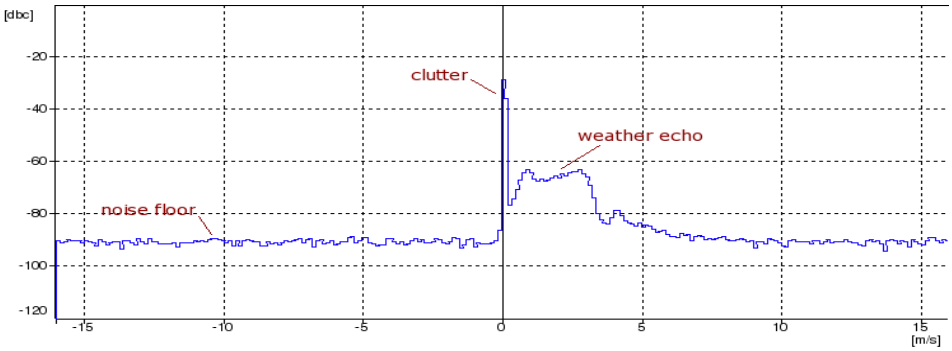


Illustration 1: Spectrum showing clutter and weather

The same weather situation with time domain clutter filter applied. The clutter peak is attenuated by 40dB but still is ~40dB above noise. The weather echo around zero velocity also was strongly attenuated.

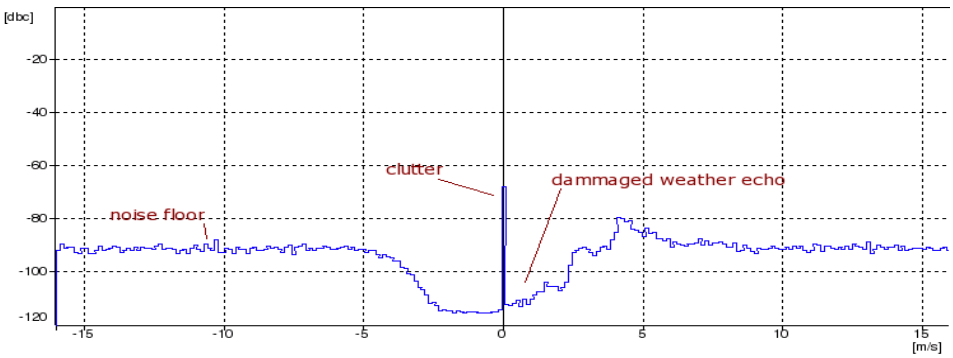


Illustration 2: Time domain filtered spectrum

The same situation again, but now filtered by spectrum interpolation. The clutter peak has been completely removed and the weather echo stayed intact.

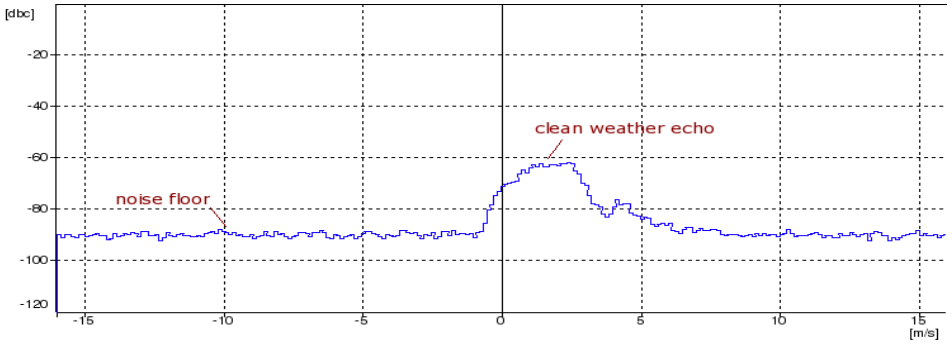


Illustration 3: Frequency domain filtered spectrum

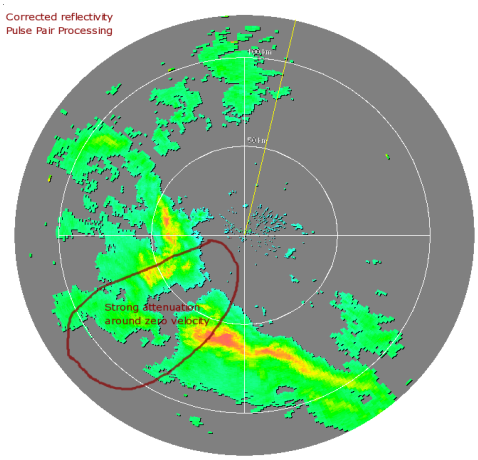


Illustration 5: PPI-Z Pulse Pair Processing

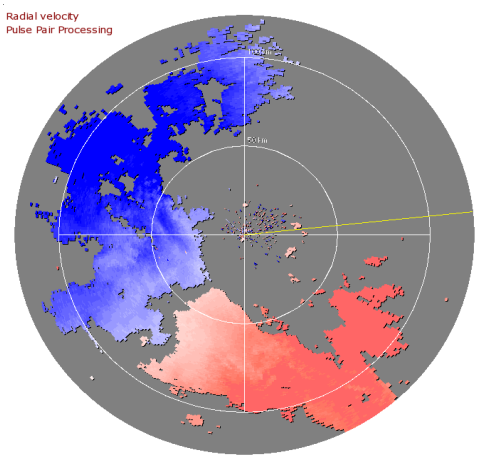


Illustration 4: PPI-V pulse Pair Processing

In the above shown examples the clutter has been removed by time domain filtering. They show strong attenuation in the weather at zero velocities.

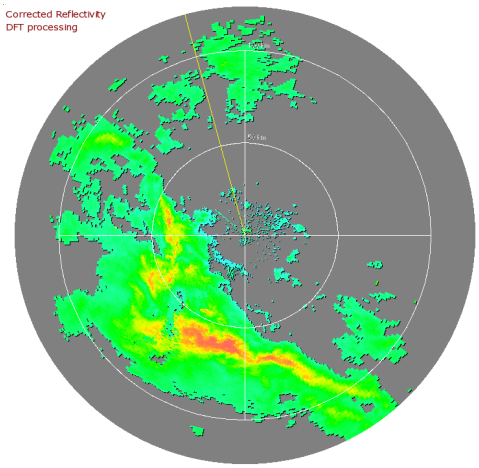


Illustration 7: PPI-Z DFT Processing

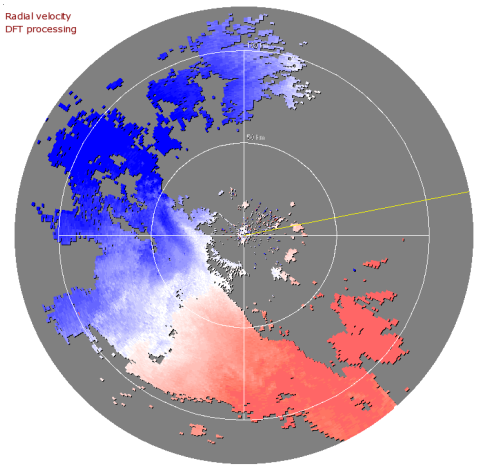


Illustration 6: PPI-V DFT Processing

The same weather situation using frequency domain filtering. The difference and the advantage of frequency domain filtering in respect to time domain filtering is quite obvious.

The ENIGMA III signal processor has the capability to output CCOR as moment. The two following images show the CCOR moment (Clutter Power) recorded with different clutter filter algorithms.

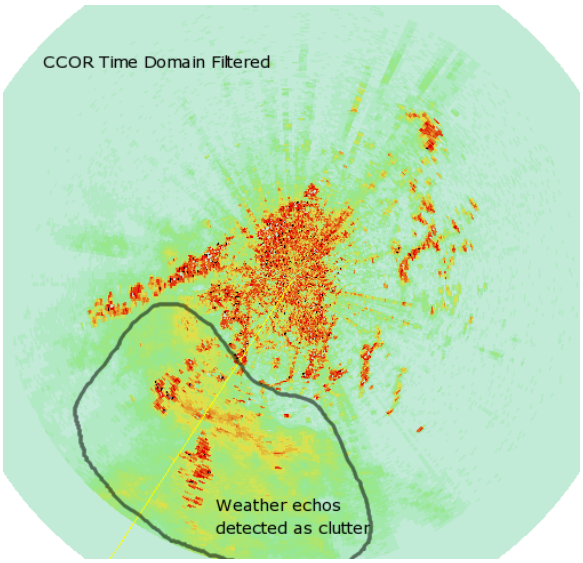


Illustration 9: PPI showing clutter power measured by time domain filtering

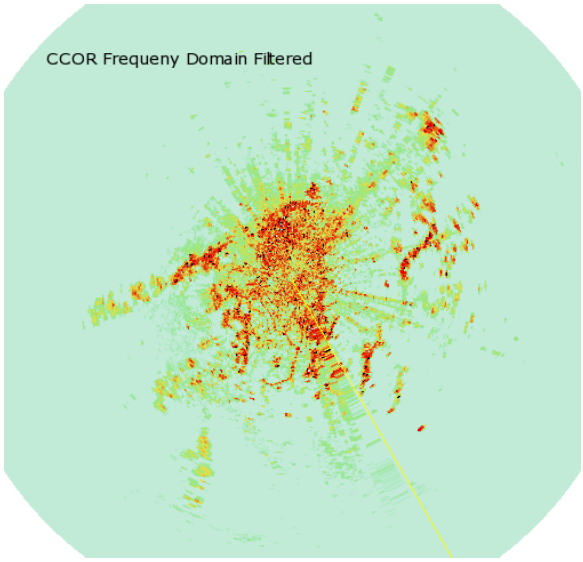


Illustration 8: PPI showing clutter power measured by frequency domain filtering

The above shown examples are actual screenshots from the FrogRT maintenance display showing a weather situation recorded in June 2007 in Germany. Data courtesy Deutscher Wetterdienst (DWD)

2.1.7 Adjusting velocity thresholds

Open an A-Scope or a PPI for radial velocity (V) and observe the effects of the following parameter.

2.1.7.1 SQI Threshold Parameter

The SQI threshold parameter can be adjusted from 0 to 1. 0 is a signal, containing only noise, whereas 1 is a „pure“ tone signal. Typically this threshold is set to 0.4..0.5, depending on the signal quality.

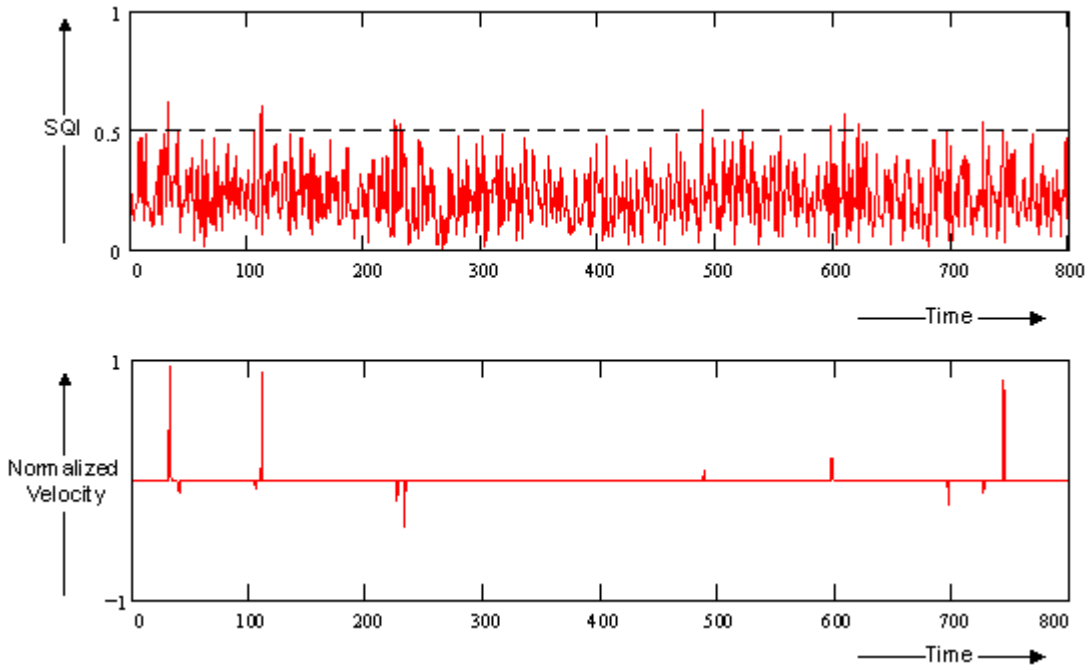


Illustration 10: SQI A-Scope

The figure above shows the calculated signal quality index SQI over time. The data where acquired from a radar receiver I/Q baseband output (only noise). When setting a SQI threshold of 0.5 and enabling V threshold flag for SQI, most velocity speckles will be removed.

- Select 0.0 for SQI threshold parameter.

- Select SQI for V threshold flags.
- Select IQ clutter All pass.
- Click on Apply.
- Now, you will see a very noisy A-Scope for the radial velocity.

Increase the SQI threshold to 0.4.

The noise in the A-Scope almost disappears. Fine-tune the SQI parameter, until the noise is almost removed completely.

2.1.7.2 Clutter threshold Parameter

Only the CCOR clutter threshold and the IQ clutter filter configuration is relevant for rejecting zero velocity (clutter).

See description for CCOR threshold and IQ clutter filter above.

- Set CCOR threshold to –30dB.
- Select IQ clutter filter to All pass.
- Select SQI | CCOR for V threshold flags.
- Click on Apply in the extended SDP settings.

If you can identify a strong clutter target in the closer area of the radar, the radial velocity in the A-Scope indicates a value around zero (= clutter).

- Select IQ clutter filter IQ3.
- Click on Apply in the extended SDP settings.

If you can identify a strong clutter target in the closer area of the radar, the radial velocity in the A-Scope will be thresholded (= rejected).

2.1.8 Adjusting spectral width thresholds

The thresholding of spectral width data is the same as for radial velocity. See description above.

2.2 Reflectivity and Doppler speckle remover

Speckle removers can be applied to all final physical moments (Z, UZ, V, W). They can be switched on or off separately for reflectivity and Doppler results. Speckle removers identify isolated valid bins in the output data ray. In that case, they are removed and flagged as unvalid (or thresholded).

The speckle remover removes isolated valid data range bins, whose neighbors have been thresholded before (NOISE threshold, CCOR threshold...). The reflectivity speckle remover can be applied to corrected and uncorrected reflectivity data (Z and UZ). The Doppler speckle remover can be applied to radial velocity (V) and spectral width data (W).

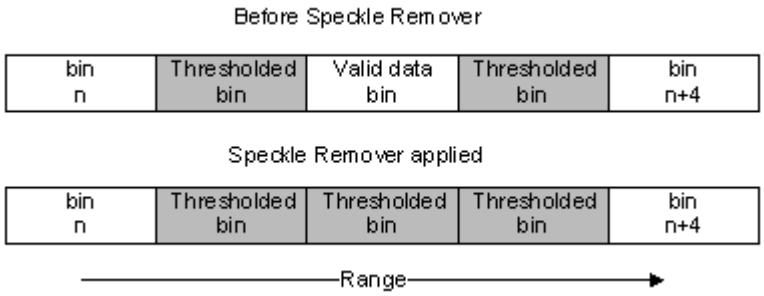


Illustration 11: Speckle remover

Parameters:**SpeckleRemoverZ** and **SpeckleRemoverV**

2.3 Averaging

The SDP configuration parameter include the range sample and time sample parameter. Note, sometimes "range sample" is also referred to "range averaging" and time sample is also referred to "time averaging". The figure below explains both parameters. The number of time samples is equivalent to the number of pulses, which are used for averaging. The number of range samples is equivalent to the number of consecutive range bins, which are averaged together in order to output 1 range bin for the physical moments Z,V,W. In the figure below, range sample is 5, assume the range step is configured for 125 meter. First the signal processor averages the number of time samples (=pulses) for each range bin. Then, the signal processor averages 5 range bins together. The resolution of the output data (physical moments Z,V,W) is (5-1)x125 meter = 500 meter. When setting range sample to zero, no range averaging is applied and the output resolution is equal to the configured rangestep.

2.3.1 Time averaging

Time averaging can be configured from 8 up to 256. This parameter is equivalent to the number of coherently integrated pulses for the AKF's. In case of dynamic angle syncing mode, the number of pulses integrated, depends on the selected angle step, PRF and antenna speed.

Parameter: **SyncModeParam**

2.3.2 Range averaging

Range averaging can be configured from 1 to 40. A value of 1:q

means, that no range averaging is done. A value of 2 means, that 2 consecutive bins are averaged together in order to form one output range bin. The range averaging is applied on the AKF's result.

Parameter: **RangeSample**

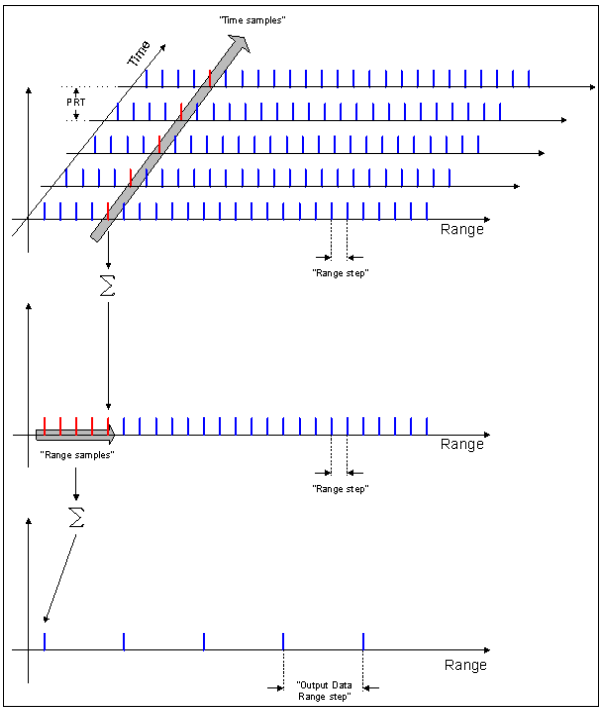


Illustration 12: Time and range averaging

2.4 Doppler clutter filters

Doppler clutter filtering is based on the valid assumption that stationary ground targets appear as strong narrow peaks around zero in the spectrum (sampled over the PRT).

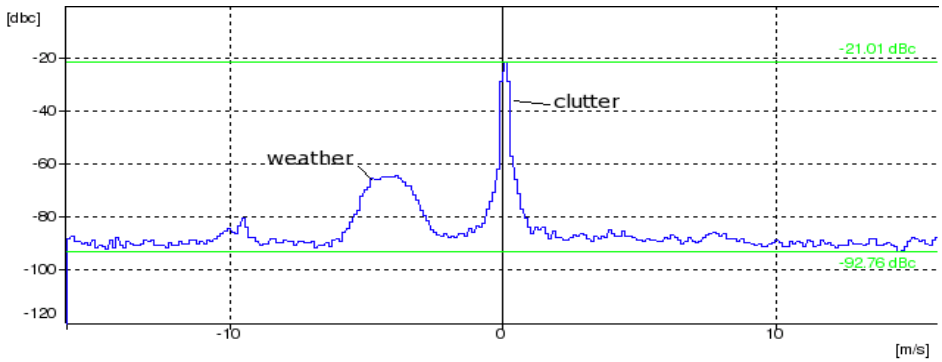


Illustration 13: Typical spectrum showing weather and clutter targets

The doppler clutter filter (both time- and frequency- domain processing) attenuate the radar signal around the zero frequencies. Time domain processing applies a configurable highpass filter to the radar data. This attenuates **all** DC components in the signal, regardless if they are due to clutter or weather. The frequency domain filter work on the above mentioned assumption and are able to separate weather and clutter targets.

2.4.1 Time domain filtering

The pulse-pair processing performs as a first stage filtering of the input data. It has an implementation of the digital infinite impulse response (IIR) filters. There are seven 40 dB and seven 50 dB 4-order Chebyshev highpass filters. The coefficients can be chosen with the parameter '**ClutterFilter**'.

0 and 8 – no filtering;

from 1 to 7 – one of 40 dB filter;

from 9 to 15 – one of 50 dB filter.

Additional parameter are **ZeroFilter** and **FilterDelay**. When using PRF staggering it is recommended to use the **ZeroFilter** and **FilterDelay** parameter as consecutive rays are sampled with a different sampling frequency (PRF). The recursive filters must be reset to avoid artifacts.

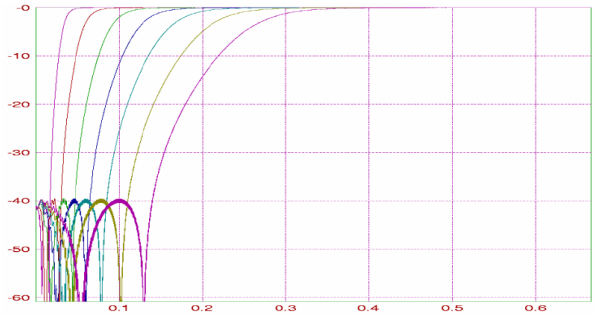


Illustration 14: 40 dB IIR clutter filter

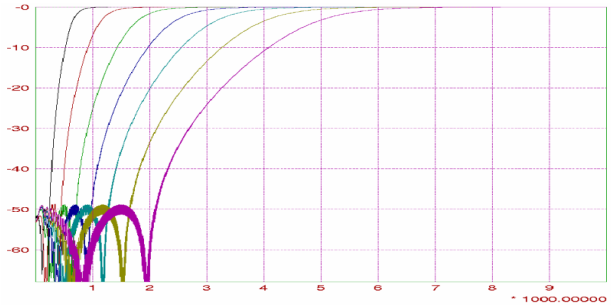


Illustration 15: 50 dB IIR clutter filter

The figure below shows the digital clutter filter structure for the time domain filtering. The coefficients determine the filter characteristics. Seven different high pass filter are selectable. Please refer to the chapter Pulse Pair processing, DFT processing and FFT processing for further details.

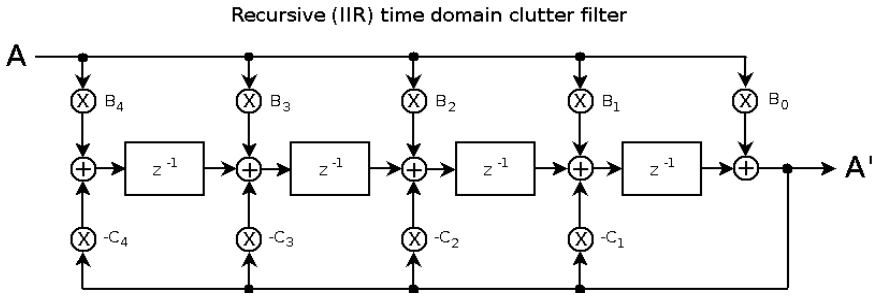


Illustration 16: IIR time domain clutter filter

$A'_n = B_0A_n + B_1A_{n-1} + B_2A_{n-2} + B_3A_{n-3} + B_4A_{n-4} - C_1A'_{n-1} - C_2A'_{n-2} - C_3A'_{n-3} - C_4A'_{n-4}$

A_n are the unfiltered samples, A'_n are the filtered samples, B_0-B_4 and C_1-C_4 are the coefficients of the IIR filter

Parameter: **ClutterFilter**, **MaxFilterRange**, **ZeroFilter** and **FilterDelay**

2.4.2 Frequency domain filtering

For frequency domain filtering several different algorithms have been implemented the algorithm can be chosen with the parameter **InterpolationMode**.

2.4.2.1 DC Cancelation

This is the simplest frequency domain filter. It is basically a highpass filter (like the timedomain IIR filter) with infinite stopband attenuation. According to the specified filter width the taps around frequency 0 are zeroed. The filter is not adaptive and might introduce ringing (**Gibbs** Phenomenon)

2.4.2.2 Half plane subtraction

Half plane (*Passarelli et al 1981*) subtraction removes symetric components around zero from the spectrum. This includes the symetric clutter peaks and sidelobes and unfortunately weather echoes with zero radial velocity. This filter is adaptive.

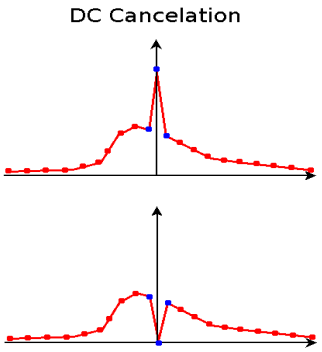


Illustration 17: DC cancelation

2.4.2.3 Interpolation

Beginning at frequency zero the minimum is searched (in both directions) up to a maximum width (see filter number). The center pixels are discarded and replaced by a linear interpolation. This filter is adaptive.

2.4.2.4 Dual slope search interpolation

This filter works similar to the interpolation above. The difference is that it tries to interpolate across the first sidelobe (introduced by the strong clutter target). This filter is adaptive.

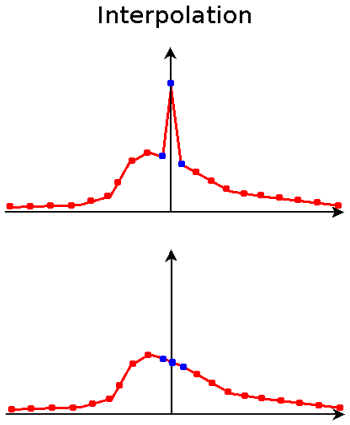


Illustration 18: Spectrum interpolation

2.4.2.1 Windowing

To suppress sidelobes it is necessary to apply a tapering window to the data prior to the transformation into the frequency domain.

Window functions generally have a maximum value centered on the time series and are tapered near zero at the ends. This tapering reduces the spectrum smearing a leakage of spectral energy introduced by the discontinuity imposed by sampling when the end points are joined.

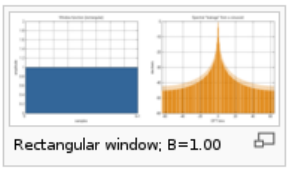
The type of window function is chosen by the parameter **FFTWindow**.

FFTWindow

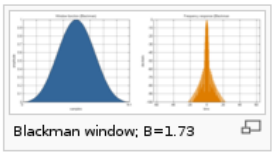
Possible values are:

0 – Rectangular
1 – Hamming
2 – Blackman
3 – Hann
4 – Welch
5 – Kaiser-Bessel

Rectangular window



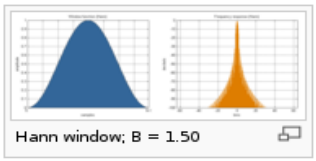
Blackman window



$$w(n) = a_0 - a_1 \cos\left(\frac{2\pi n}{N-1}\right) + a_2 \cos\left(\frac{4\pi n}{N-1}\right)$$

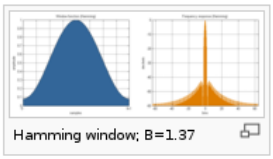
$$a_0 = 0.42; \quad a_1 = 0.5; \quad a_2 = 0.08$$

Hann window



$$w(n) = 0.5 \left(1 - \cos\left(\frac{2\pi n}{N-1}\right)\right)$$

Hamming window



$$w(n) = 0.53836 - 0.46164 \cos\left(\frac{2\pi n}{N-1}\right)$$

Terminology**:**

- N represents the width, in samples, of a discrete-time window function. Typically it is an integer power-of-2, such as $2^{10} = 1024$.
- n is an integer, with values 0<=n<=N-1. So these are the time-shifted forms of the windows**:** $w(n)=w_0(n-(N-1)/2)$, where w(n) is maximum at n=0.
- Some of these forms have an overall width of $N-1$, which makes them zero-valued at $n=0$ and $n=N-1$. That sacrifices two data samples forno apparent gain, if the DFT size is N. When that happens, an alternative approach is to replace $N-1$ with N in the formula.
- Each figure label includes the corresponding noise equivalent bandwidth metric (B), in units of *DFT bins*. As a guideline, windows are divided into two groups on the basis of B. One group comprises 1<=B<=1.8 , and the other group comprisesB>=1.98 . The Gauss and Kaiser windows are families that span both groups, though only one or two examples of each are shown.

Parameter: **ClutterFilter**, **MaxFilterRange, FFTWindow** and **InterpolationMode**

2.5 Pulse-pair processing.

The basis for time domain moment estimation is the transform relationship of the autocorrelation function of the complex signal to the power spectrum.

The estimate of the autocorrelation can be calculated from the complex input time series at the given range as following:

$$T_0 = \frac{1}{N} \sum_{k=0}^{N-1} s_k^* s_k$$

$$R_m = \frac{1}{(N-m)} \sum_{k=0}^{N-m-1} s_k'^* s_k'$$

Where:

M	number of pulses for averaging
s_k	represents unfiltered I and Q samples
s'_k	represents filtered I and Q samples
*	complex conjugation
g	system gain
S	signal power
C	clutter power and N is a noise power.
T_0	unfiltered signal power = g(S+C)+N
R_0	filtered signal power = gS+N
R_1	first lag of a filtered signal power =g S exp[j π V'-π^2 W^2/2]
R_2	second lag of a filtered signal power = g S exp[j 2π V'-2$\pi^2$$W^2$]

It is well known that the first few lags of the autocorrelation function are sufficient to find a Doppler velocity and spectrum width. So, it is enough to calculate T_0, R_0, R_1, R_2.

V' is the mean velocity in the sampling volume and W is the mean spectrum width. Radial velocity in the normalized Nyquist interval from -1 to 1 and spectrum width in the normalized Nyquist interval [0,1].

Parameter: **AcfMode**

2.6 DFT processing.

The Doppler power spectrum may be estimated from the Discrete Fourier Transform (DFT) of the complex signal.The DFT decomposes the observed data into a sum of sinusoids having amplitude and phase that will exactly reproduce the observed data. These N discrete components are adequate to reconstruct the entire continuous spectrum as long as the complex data samples are taken at a rate equal to or greater than the bandwidth of a signal (Which is typically 500kHz - 2MHz).

The autocorrelations are calculated using the Wiener–Khinchin theorem, which relates the autocorrelation function to the power spectral density via the Fourier transform:

$$R(\tau) = \int_{-\infty}^{\infty} S(f) e^{j2\pi f\tau}\, df$$

The advantage of measuring the full Doppler spectrum is that spectral impurities, such as ground clutter, can be easily suppressed by algorithms. When highly coherent spectral components (e.g., clutter) are present, the correlation usually will not decay to zero within N samples.

Processing stages of the DFT algorithm:

1) applying window function on the input data;
2) forward DFT;
3) filtering;
4) inverse DFT, which produces autocorrelations.

Parameter: **AcfMode**

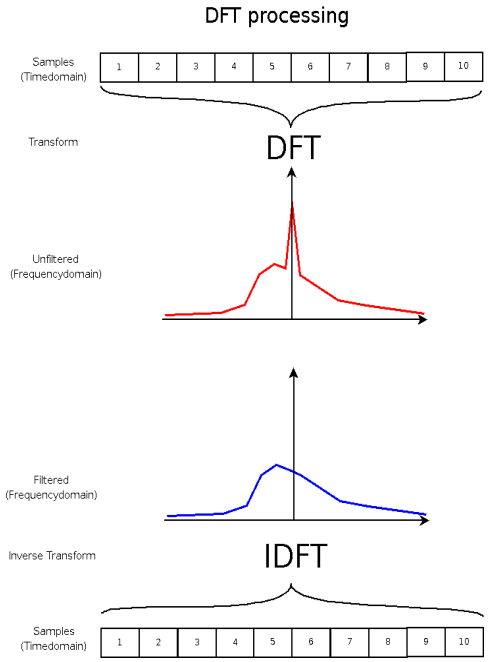


Illustration 19: DFT processing

2.7 FFT processing.

The above described DFT (Discrete Fourier Transform) processing needs a lot of CPU resources. In case the DFT processing can't manage the acquired data, some optimizations can be used. DFT works on the number of samples being a power of 2 faster than on an arbitrary number of samples. This optimization is called FFT(Fast Fourier Transform)

The data is split into two overlapping groups, both groups have a 'power of 2' number of samples. Previously described DFT (now FFT) performed on both groups and then results are averaged.

If the number of samples is exactly a power of 2, then no splitting is needed.

Parameter: **AcfMode**

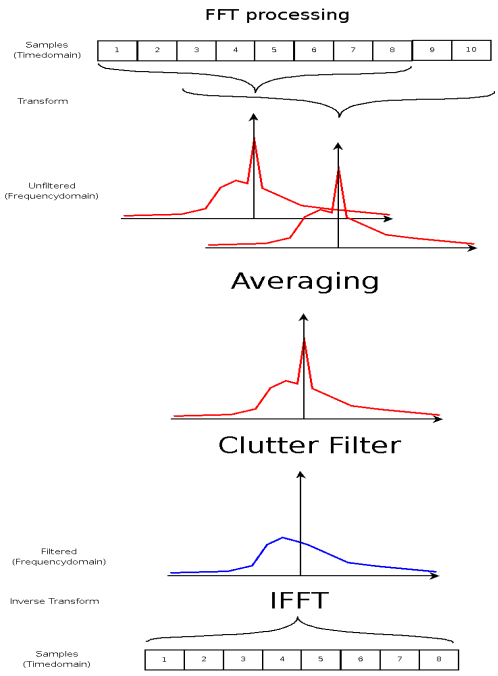


Illustration 20: FFT processing

2.8 Range-Doppler Dilemma

The physical relationship between the unambiguous range and unambiguous velocity limits the dynamics of the acquired data. An example is shown in the diagram below. The unambiguous velocity can be increased with the staggered PRF algorithm. The unambiguous range can be increased by reducing the PRF (This also reduces the unambiguous velocity)

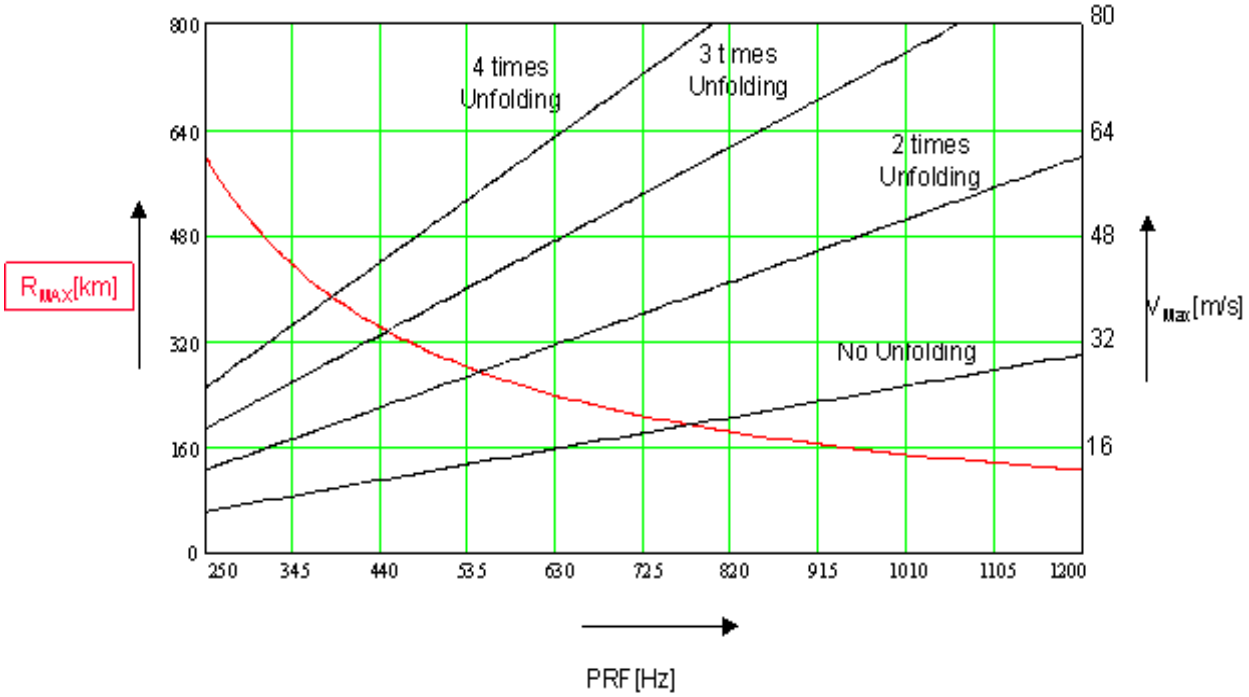


Illustration 21: Range doppler dilemma

2.9 Calibration

Calibrated reflectivity data [dBZ] are calculated from the meteorological radar equation.

The radar equation:

$P_r = C \cdot Z_E \cdot \frac{1}{r^2}$ ZE: The sum of all particles within 1m^3

or

$dBZ = 10 \cdot \log(\frac{P_r}{C} \cdot r^2)$ Logarithmic reflectivity

$$C = \frac{\pi^3 \cdot P_t \cdot G^2 \cdot \phi \cdot \varphi \cdot c_l \cdot \tau}{1024 \ln(2) \cdot \lambda^2}$$

P_t : *Transmitted Peakpower* [W]
G: *AntennaGain*
ϕ: *Horizontalhalf – power beamwidth* [*degree*]
φ: *Verticalhalf – power beamwidth* [*degree*]
c_l : *Speedof light* = $3 \cdot 10^8 m/s$
λ: *Radartransmitted wavelength* [m]
τ : *Pulsewidth* [s]

Illustration 22: Radar equation

Please refer to the FrogRT user manual for more details about calibration and how to perform it.

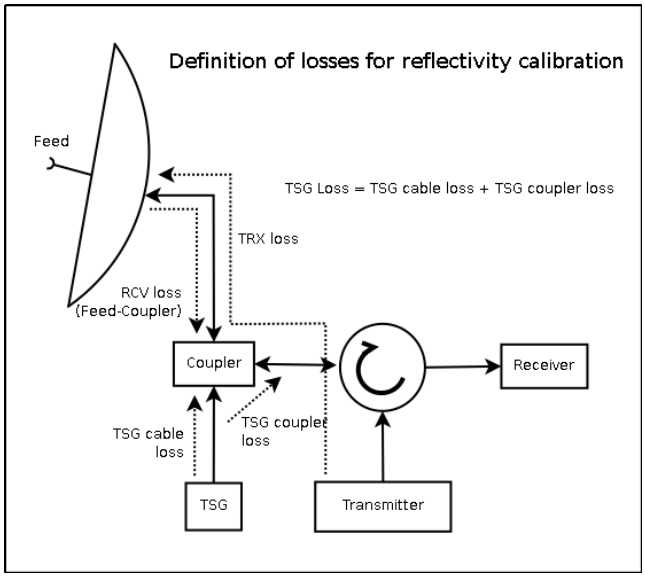


Illustration 23: Definition of radar losses

2.10 Dynamic Angle Syncing

Dynamic angle syncing mode is used for data acquisition. One ray consist of the number of pulses which fall in one angle sector.

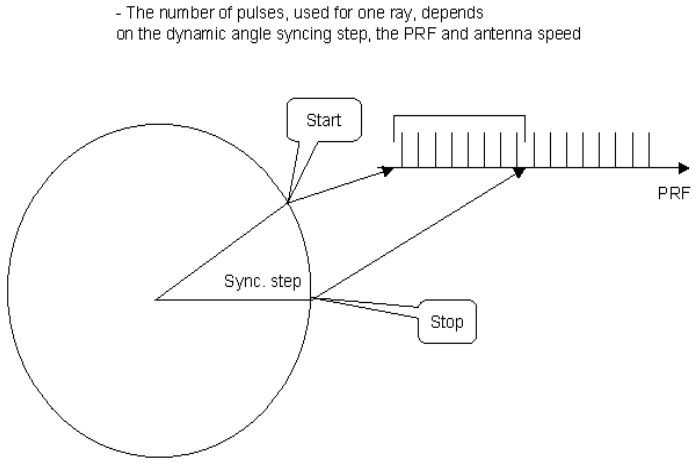

- The number of pulses, used for one ray, depends
on the dynamic angle syncing step, the PRF and antenna speed
Start
PRF
Sync. step
Stop

Illustration 24: Dynamic angle syncing

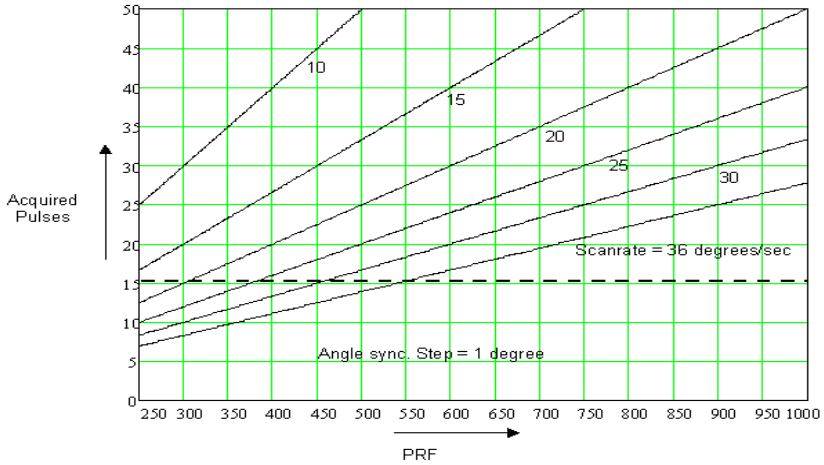


Illustration 25: Integrated pulses versus PRF and scanrate

2.11 Dual PRF Unfolding

In order to increase the mean velocity dynamic range, the dual PRF unfolding algorithm (= staggered PRF) has been implemented.

Three modes are available:

- Two times unfolding (2/3 stagger staggering; increases velocity dynamic range by factor 2)
- Three times unfolding (3/4 staggering; increases velocity dynamic range by factor 3)
- Four times unfolding (4/5 staggering; increases velocity dynamic range by factor 4)

-Measured radial velocity (No Unfolding) :

$$v = \frac{\lambda}{4\cdot\pi}\cdot prf\cdot\theta$$

v : $Radialvelocity$

λ : $Radarwavelength$

θ : $\arg(R1)$

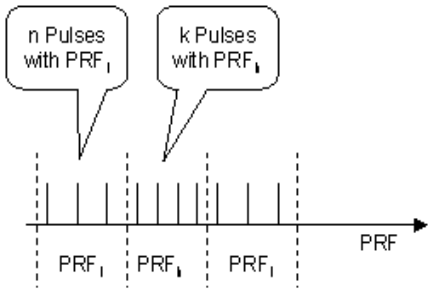
$$\theta = \pi \Rightarrow v_{Max}$$

$$v_{Max} = \frac{\lambda}{4\cdot\pi}\cdot prf$$

-Measured radial velocity (Unfolding) :

$$\theta_l = \frac{4\cdot\pi\cdot v}{\lambda\cdot prf_l}$$

$$\theta_h = \frac{4\cdot\pi\cdot v}{\lambda\cdot prf_h}$$



$$\Delta\theta = \theta_l - \theta_h = \frac{4\cdot\pi\cdot v}{\lambda}\cdot\left(\frac{1}{prf_h} - \frac{1}{prf_l}\right) \qquad v_{MaxUnfold} = \frac{\lambda}{4}\cdot\frac{1}{\frac{1}{prf_l} - \frac{1}{prf_h}}$$

Illustration 26: Dual PRF unfolding

Parameter: **PrfLimits** and **PrfTab**

2.12 Default values for the extended SDP parameter

Default values for the extended parameters can be obtained from the table below, but keep in mind, that optimal values can only be obtained by adjusting each parameter according to the specific requirements. Each site needs different parameter for optimum performance.

Clutter Micro Suppression	On	Only when RangeSampling is selected
Clutter MicroSuppression Threshold	30 dB	
Reflectivity Speckle Filter	On	
Velocity Speckle Filter	On	
Zero Filter	Off (Single PRF) On (PRF staggering)	For Pulse Pair Processing
Filter Stabilization Delay	>4	For Pulse Pair Processing
NOISE Threshold	1 dB	
SQI Threshold	0.4	
CCOR Threshold	-40 dB	
IQ Clutter Filter	IQ 3	DFT or FFT processing IQ5
Z Threshold Flags	NOISE | CCOR	
V Threshold Flags	SQI | CCOR	
W Threshold Flags	SQI | CCOR	
UZ Threshold Flags	NOISE	
Gas attenuation	0.016 dB/km	For C-Band

3 Network

Network is configured in the file /etc/conf.d/net. The file looks as follows. Here a static IP address or DHCP can be configured. Just comment out the corresponding lines.

/etc/conf.d/net:

```
# To avoid delay on booting, use the fixed address configuration
# and comment out the dhcp/fallback part

# Static IP address
#config_eth0=( "192.168.3.11 netmask 255.255.255.0" )
#route_eth0=( "default via 192.168.3.254" )

# DHCP configuration
config_eth0=( "dhcp" )
dhcpcd_eth0="-t 10 -L"
#fallback_eth0=( "192.168.3.11 255.255.255.0" )
#fallback_route_eth0=( "default via 192.168.3.1" )
```

In case of problems the ENIGMA host PC can be booted into single user mode. Connect a keyboard and a monitor (or s serial terminal) to the ENIGMA PC and enter `softlevel=single` in the GRUB boot menu.

4 SDP settings

SDP settings are stored in the file /opt/enigma3/controlagent.is

All SDP parameters are saved at the exit and restored automatically on start.

This file contains list of 'set' commands to set all the parameters to specified values.

At run-time settings can be saved and loaded with corresponding 'save' and 'load' command. They don't have arguments.

See 'Parametrization' section for detailed syntax.

5 SDP interfaces

SDP has two network TCP interfaces:

1) command interface – for control and parametrization.
2) acquisition interface – to receive the acquired rays.

5.1 Command interface

SDP is controlled by text commands via network session. Network session has a following steps:

1) connection
2) authorization
3) parametrization
4) acquisition

5.1.1 Connection

5.1.1.1 Browser interface

Most of the parameters described in the following section also can be accessed through a comprehensive HTTP interface. Just point your browser at the IP address of the ENIGMA3 signal processor giving the port number 30000

Example: http://enigma3.gamic.com:30000

5.1.1.2 Telnet

SDP listens on TCP port 5555. Frog-Muran software connects as a TCP client to this port. For test and maintainance purposes 'telnet' client can be used.

Connect to 'enigma3' host as following:

```
telnet enigma3 5555
```

5.1.1.3 Authorization

When the command conenction is established, SDP provides its information:

```
auth ControlAgent
```

The command for authorization is '`auth <ClientType>`'

SDP authorizes two types of clients.

1) Controller.
2) Secondary.

'Controller' means, that SDP binds acquisition and command interface in one logical session. If command interface is closed by the client, SDP closes the acquisition connection. It is designed for use in Frog-Muran software. It is important to have only one Controller connection at a time!

'Secondary' doesn't have this restriction. It is used for tests and maintenance.

Example:

```
auth Controller
```

6 Parametrization

There are many commands and parameters supported by the SDP.

The list of commands and parameters with short descriptions can be obtained through the 'help' command:

help

SDP responds with a text similar to the shown below::

```
Format: help [<command_name> | <param_name>]
Where command_name is:
get: get parameter
getadcdiff: get phase and power difference for hi/lo channels
getafcstatus: Get AFC status
getasciistatus: Request status from IFD and PCI receiver
getburst: get burst parameters
getconverter: converter status
geterrorconditions: Get error conditions
getifsampling: Get IF Sampling Parameters
getpower: power status
gettemperature: temperature
getversion: get hardware version numbers
load: load parameters
noisesample: Noise sampling
sampleburst: get burst samples
save: testsave parameters
set: set parameter
setafcmode: Set AFC Mode
setpulsewidth: Set Pulse Width Index
settxdtrigger: Set TxD trigger
startacq: start acquisition
stopacq: stop acquisition

param_name is:
AFCSettings: AFC settings
AcfMode: ACF mode
AzimuthAbsoluteOffset: calibratiobn offset for antenna alignment
AzimuthSynchroOffset: calibratiobn offset for encoder/synchro diference
BurstTiming0: burst sample timing
BurstTiming1: burst sample timing
BurstTiming2: burst sample timing
BurstTiming3: burst sample timing
CCORThreshold: CCOR threshold
ClutterFilter: Clutter filter number
ClutterMicroSuppression: Set clutter micro suppression
ClutterMicroSuppressionThreshold: Clutter micro suppression threshold
```

DataFormat: Frog output data format type
DualPolMode: dual polarization mode
ElevationAbsoluteOffset: calibratiobn offset for antenna alignment
ElevationSynchroOffset: calibratiobn offset for encoder/synchro diference
FFTWindow: Type of smoothing window for FFT and DFT ACF algorithms
FIRCoeff0: FIR coefficients for pulse 0
FIRCoeff1: FIR coefficients for pulse 1
FIRCoeff2: FIR coefficients for pulse 2
FIRCoeff3: FIR coefficients for pulse 3
FilterDelay: IIR filter delay
HorVerSwitchDuration: Duration for MOHP Hor/Ver switching device in ms
IFDTagBaudRate: Baud rate IFD
InterpolationMode: FFT/DFT Interpolation method
LdrOffset: LDR offset
LongRaySize: If true, use 32bit raysize word
MaxFilterRange: Maximum filter range
NOISEThreshold: NOISE threshold
PCIRecTagBaudRate: Baud rate PCIREC
PRFTable: PRF table
PhidpOffset: PhiDP offset
PhidpSNR: Phidp SNR threshold
PrfLimits: PRF limits
PulseWidthIndex: PulseWidthIndex
RHOHVThreshold: RHOHV threshold
RainAttenuation: Rain attenuation correction
RainAttenuation_A: RainAttenuation_A
RainAttenuation_B: RainAttenuation_B
RainAttenuation_a: RainAttenuation_a
RainAttenuation_b: RainAttenuation_b
Range: Range for acquisition in km
RangeAdjust0: Range adjustment
RangeAdjust1: Range adjustment
RangeAdjust2: Range adjustment
RangeAdjust3: Range adjustment
RangeNorm: Range normalisation
RangeSample: Range samples
RangeStep: Range step in km.
RaySize: expected ray size
RecordName: file to save recorded raw data
RecorderMode: filenameRecorder mode
SDPType: SDP Type
SQIThreshold: SQI threshold
SectorblankingTable: Flags for 2D sectorblanking table
SectorblankingTableEnabled: Sector blanking on/off
SmoothDualPolParameter: Apply smoothing filter to KDP, RHOHV and ZDR
SpeckleRemover2D: 2D speckle remover
SpeckleRemoverV: Doppler speckle remover

```
SpeckleRemoverZ: Reflectivity speckle remover
SyncModeParam: Sync mode
TagConfiguration: Serial TAGS configuration
Trig0Duration: Tigger 0 duration
Trig0Enable: Tigger 0 enable/disable
Trig0Invert: Tigger 0 invert
Trig0Start: Tigger 0 start
Trig1Duration: Tigger 1 duration
Trig1Enable: Tigger 1 enable/disable
Trig1Invert: Tigger 1 invert
Trig1Start: Tigger 1 start
UDPTagsHost: host that sends tags in UDP
UDPTagsPort: localhostport for UDP tags
ZdrOffset: ZDR offset
ZeroFilter: Clear IIR filter for every ray
dbz0: DBZ0
gasAttenuation: Gas Attenuation
noisePowerH: linear noise power horizontal
noisePowerV: linear noise power vertical
thresholdFlagsTable: Threshold flag table
To set a parameter type: set <param_name> <value>
To get a parameter type: get <param_name>
```

SDP responds:

```
get errormsg=null <Parameter>=<Value>
```

if successfull, or

```
get errormsg='<error text>'
```

if failed.

Commands start some actions.

General syntax is:

```
<Command> [<Arg>=<Value> ...]
```

SDP responds:

```
<Command> errormsg=null [<Arg>=<Value> ...]
```

if successful, or

```
<Command> errormsg='<error text>'
```

if failed

6.1 Klystron related parameter

The following parameter can be configured for a Klystron system:

1) These parameter are only available if **SDPType** equals **13**
2) After setting the parameters the command **setpulsewidth** has to be called (it will perform the calculation of the burst coefficients and upload them to the COHO card)
3) The ENIGMA host PC must be equipped with the COHO card option.

6.1.1 KlystronGateDuration*X*

Duration of the gate signal in µs (0.2µs...50µs in 10ns increments). **X represents the pulse width index (0-3).** After setting the parameters the command setpulsewidth has to be called (it will perform the calculation of the burst coefficients and upload them to the COHO card)

Type: **float**
Default: **1**
Unit: **µs**

6.1.2 KlystronGateStartX

Start of the gate signal (in respect to the burst start) in µs (-20µs...20µs in 10ns increments). **X represents the pulse width index (0-3).** After setting the parameters the command setpulsewidth has to be called (it will perform the calculation of the burst coefficients and upload them to the COHO card)

Type: **float**
Default: **0**
Unit: **µs**

6.1.3 KlystronPulseDurationX

Length of the burst in µs (0.2µs...9.5µs in 10ns increments). **X represents the pulse width index (0-3).** After setting the parameters the command setpulsewidth has to be called (it will perform the calculation of the burst coefficients and upload them to the COHO card)

Type: **float**
Default: **1**
Unit: **µs**

6.1.4 KlystronTaperingStartX

Tapering percentage for the start of the burst (0...100% 100% means that the tapering is performed from the start of the burst up to the middle of the burst). **X represents the pulse width index (0-3).** After setting the parameters the command setpulsewidth has to be called (it will perform the calculation of the burst coefficients and upload them to the COHO card)

Type: **float**
Default: **0**
Unit: **%**

6.1.5 KlystronTaperingStopX

Tapering percentage for the end of the burst (0...100% 100% means that the tapering is performed from the middle of the burst up to the end of the burst). **X represents the pulse width index (0-3).** After setting the parameters the command setpulsewidth has to be called (it will perform the calculation of the burst coefficients and upload them to the COHO card)

Type: **float**
Default: **0**
Unit: **%**

6.1.6 KlystronWindowTypeStartX

Select taper function for start tapering (0: Linear, 1: Hamming, 2: Blackman). **X represents the pulse width index (0-3).** After setting the parameters the command setpulsewidth has to be called (it will perform the calculation of the burst coefficients and upload them to the COHO card)

Type: **int**
Default: **0**

6.1.7 KlystronWindowTypeStopX

Select taper function for stop tapering (0: Linear, 1: Hamming, 2: Blackman) **X represents the pulse width index (0-3).** After setting the parameters the command setpulsewidth has to be called (it will perform the calculation of the burst coefficients and upload them to the COHO card)

Type: **int**
Default: **0**

The following command sequence will configure pulse width 0 for a 1µs burst with a gate signal

matching the burst exactly in time and 25% of linear tapering at both sides of the burst (25% tapering for a burst duration of 1µs means tapering for 0.5µs * 0.25 = 0.125µs)

```
set KlystronGateDuration0 1
set KlystronGateStart0 0
set KlystronPulseDuration0 1
set KlystronTaperingStart0 25
set KlystronTaperingStop0 25
set KlystronWindowTypeStart0 0
set KlystronWindowTypeStop0 0
setpulsewidth 0
```

6.2 Trigger

The IFD module provides 2 additional configurable 5V @ 50Ω (15V optional) trigger. These trigger signals have a configurable duration and the timing of the leading edge (in respect to the master trigger from the PCI receiver card) can be configured too. The following parameter are used to configure the triggers.

6.2.1 TrigXEnable

Enable/disable trigger x (e.g. Trig0Enable or Trig1Enable)

Type: **boolean**
Default: **false**

6.2.2 TrigXDuration

Duration of the trigger in µs (range 0...100µs). Resolution approx. 15ns

Type: **float**
Default: **1**
Unit: **µs**

6.2.3 TrigXStart

Start of the leading edge in respect to the leading edge of the master trigger. (range -100...100 µs)

Type: **float**
Default: **0**
Unit: **µs**

6.2.4 TrigXInvert

Invert the trigger (When this trigger is disabled the output stays in a low state, regardles of the content of this parameter.

Type: **boolean**
Default: **false**

6.3 Sector blanking

Sector blanking is configured through a azimuth versus elevation table providing a 1° resolution in azimuth and a 0.5° resolution in elevation. The azimuth range is obviously 360° and the elevation range is from -5° to 45°.

6.3.1 SectorblankingTable

Type: **table**
Default: **empty table**

The table is a bit mask coded in unsigned 32bit values. Per elevation step 360 values need to be coded. This leads to 12 unsigned 32bit values (padded to 32bit) . The bits are ordered in clockwise azimuth starting at 0° (MSB first). The full table has a length of 12x100 32bit values. The table starts at -5° elevation.

Example:

The following table codes sector blanking in the range 10°-16° azimuth (one elevation step only)

Bits:

0000000000111111 1000000000000000 0000000000000000 0000000000000000 0000000000000000 0000000000000000 0000000000000000 0000000000000000 0000000000000000 0000000000000000 0000000000000000 0000000000000000

Values:

0x003f 0x8000 0x0000 0x0000 0x0000 0x0000 0x0000 0x0000 0x0000 0x0000 0x0000 0x0000

Remark: The values have to be given as decimal number
(not in HEX as shown above)

Example:

Configure sector blanking for a sector 10°-16° azimuth forelevation -5° to 3°.

```
set SectorblankingTable 63 32768 0 0 0 0 0 0 0 0 0 0 63 32768 0 0 0 0
0 0 0 0 0 0 63 32768 0 0 0 0 0 0 0 0 0 0 63 32768 0 0 0 0 0 0 0 0 0 0
63 32768 0 0 0 0 0 0 0 0 0 0 63 32768 0 0 0 0 0 0 0 0 0 0 63 32768 0 0
0 0 0 0 0 0 0 0 63 32768 0 0 0 0 0 0 0 0 0 0 63 32768 0 0 0 0 0 0 0 0
0 0 63 32768 0 0 0 0 0 0 0 0 0 0 63 32768 0 0 0 0 0 0 0 0 0 0 63 32768
0 0 0 0 0 0 0 0 0 0 63 32768 0 0 0 0 0 0 0 0 0 0 63 32768 0 0 0 0 0 0
0 0 0 0 63 32768 0 0 0 0 0 0 0 0 0 0 63 32768 0 0 0 0 0 0 0 0 0 0 63
32768 0 0 0 0 0 0 0 0 0 0
```

Remark: Please note that only the elevation tables from -5° to 3° have been given. ENIGMA automatically fills the table with 0's at the end.

6.3.2 SectorblankingEnabled

Type: **bool**
Default: **false**

With the parameter **SectorblankingEnabled** sector blanking can be enabled/disabled. Upload the table once and use this parameter to toggle sector blanking.

6.4 Serial TAGS

As an option the ENIGMA signal processor can read the angle TAGS from a serial (RS422) line instead of the 16bit parallel TAG lines. The serial interface has several configuration options.

6.4.1 PCIRecTagBaudRate

Specify the baudrate for the RS422 TAG input at the ENIGMA host. The baudrate can be specified directly in baud (1200...4000000) and can also be a “non-standard” value like 500000 (500kbits/s).

Type: **integer**
Default: **9600**
Unit: **baud**

Remark: Only the baud rate is configurable. The other serial parameter are fixed. 1 stop bit. 1 start bit and no parity will be used.

6.4.2 IFDTagBaudRate

Specify the baudrate for the RS422 TAG input at the ENIGMA IFD+. The ENIGMA IFD III+ provides an additional input for the serial angle tags The baudrate can be specified directly in baud (1200...4000000) and can also be a "non-standard" value like 500000 (500kbits/s).

Type: **integer**
Default: **9600**
Unit: **baud**

Remark: Only the baud rate is configurable. The other serial parameter are fixed. 1 stop bit. 1 start bit and no parity will be used.

6.4.3 TagConfiguration

With ENIGMA IFD III+ the input for the angle TAGS can be freely defined. The ENIGMA IFD III only provides the option for angle TAGS at the host.

Type: **integer**
Default: **0**

Possible value:

0: Parallel tags at PCI Receiver card
1: Serial tags at PCI Receiver card
2: Serial tags at IFD *(IFD+ only)*
3: Azimuth at PCI Receiver card, Elevation at IFD *(IFD+ only)*
4: Elevation at PCI Receiver card, Azimuth at IFD *(IFD+ only)*

6.4.4 SerialTagFormat

Type: **integer**
Default: **0**

Two serial TAG formats are supported:

Data packet Format 0

7 Bytes are transmitted. First Byte is a frame syncing Byte ($80).
Byte 1 – Byte 5 contain 16 bit azimuth and elevation information:
AZ15 (MSB) - AZ0 (LSB)
EL15 (MSB) - EL0 (LSB)

The last Byte consists of a checksum calculated from Byte 0 to byte 5 (CSUM6-CSUM0).
Example for checksum:
Byte 0 : 128 (Dec)
Byte 1 : 10 (Dec)
Byte 2 : 20 (Dec)
Byte 3 : 30 (Dec)
Byte 4 : 100 (Dec)
Byte 5 : 10 (Dec)
Checksum = 128 + 10 + 20 +30 +100+10 = 298 (Dec) = 12A (Hex)

➔ CSUM = 12A (Hex) & 7F(Hex) = 2A (Hex)

Byte 0

D7	D6	D5	D4	D3	D2	D1	D0
1	0	0	0	0	0	0	0

Byte 1

D7	D6	D5	D4	D3	D2	D1	D0
0	S2	S1	S0	AZ1	AZ0	EL1	EL0

Status Bits S2-S0

0x0	Tag angle data packet
0x1-0x7	Reserved

Byte 2

D7	D6	D5	D4	D3	D2	D1	D0
0	AZ15	AZ14	AZ13	AZ12	AZ11	AZ10	AZ9

Byte 3

D7	D6	D5	D4	D3	D2	D1	D0
0	AZ8	AZ7	AZ6	AZ5	AZ4	AZ3	AZ2

Byte 4

D7	D6	D5	D4	D3	D2	D1	D0
0	EL15	EL14	EL13	EL12	EL11	EL10	EL9

Byte 5

D7	D6	D5	D4	D3	D2	D1	D0
0	EL8	EL7	EL6	EL5	EL4	EL3	EL2

Byte 6

D7	D6	D5	D4	D3	D2	D1	D0
0	CSUM6	CSUM5	CSUM4	CSUM3	CSUM2	CSUM1	CSUM0

Data packet Format 1

6 Bytes are transmitted. First Byte is a frame syncing Byte (MSB=1).
Byte 0 – Byte 4 contain 16 bit azimuth and elevation information:
AZ15 (MSB) - AZ0 (LSB)
EL15 (MSB) - EL0 (LSB)
The last Byte consists of a checksum calculated from Byte 0 to byte 4 (CSUM6-CSUM0).
Example for checksum:
Byte 0 : 131 (Dec)
Byte 1 : 10 (Dec)
Byte 2 : 20 (Dec)
Byte 3 : 30 (Dec)
Byte 4 : 100 (Dec)
Checksum = 131 + 10 + 20 +30 +100 = 291 (Dec) = 123 (Hex)

➔ CSUM = 123 (Hex) & 7F(Hex) = 23 (Hex)

Byte 0

D7	D6	D5	D4	D3	D2	D1	D0
1	S2	S1	S0	AZ1	AZ0	EL1	EL0

Status Bits S2-S0

0x0	Tag angle data packet
0x1-0x7	Reserved

Byte 1

D7	D6	D5	D4	D3	D2	D1	D0
0	AZ15	AZ14	AZ13	AZ12	AZ11	AZ10	AZ9

Byte 2

D7	D6	D5	D4	D3	D2	D1	D0
0	AZ8	AZ7	AZ6	AZ5	AZ4	AZ3	AZ2

Byte 3

D7	D6	D5	D4	D3	D2	D1	D0
0	EL15	EL14	EL13	EL12	EL11	EL10	EL9

Byte 4

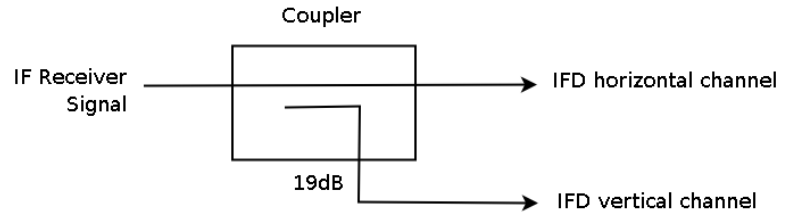
D7	D6	D5	D4	D3	D2	D1	D0
0	EL8	EL7	EL6	EL5	EL4	EL3	EL2

Byte 5

D7	D6	D5	D4	D3	D2	D1	D0
0	CSUM6	CSUM5	CSUM4	CSUM3	CSUM2	CSUM1	CSUM0

6.5 Extended Dynamic Range

In single polarization mode the ENIGMA IFD has the ability to stack two converters (Build 100 or above). The low channel is connected to the horizontal input and the high channel is connected to the vertical input.



To enable/disable the channel stacking use the **ExtendedDynamicRange** parameter.

6.5.1 ExtendedDynamicRange

Type: **boolean**
Default: **false**

There are a few configuration parameters related to this, Basically three things need to be adjusted.

The level where switching between the two ad-converters is performed. The corresponding parameter is called **PowerThreshold**.

6.5.2 PowerThreshold

Set the level (in %) for the lower channel for converter switchover

Type: **float**

Default: **70**
Unit: **percent**

6.5.3 PowerDiffH/PowerDiffV

Set the power difference between low and high channel in dBfor horizontal and vertical channel.

Type: **float**
Default: **0**
Unit: **dB**

Calibration procedure, see below.

3) The phase difference between the low and the high channel (coupler + cable)

6.5.4 PhaseDiffH/PhaseDiffV

Set the phase difference between low and high channel in degree for horizontal and vertical channel.

Type: **float**
Default: **0**
Unit: **degree**

6.5.5 Extended dynamic range calibration

The procedure is quite simple. ENIGMA measures the phase and power differences continuously. In order to calibrate please inject a **CW** signal into the IFD input that provides a power level in such a way that both converters are good power level (but not saturating). 0dBm is a good value if you have a 19dB coupler . Then you can issue the command **`getadcdiff`**.

Remark: The **`getadcdiff`** command only works if acquisition is running! There is no need to call **`stopacq`**.

Example:

```
getadcdiff
```

```
getadcdiff errormsg=null phaseDiffH=12.56 phaseDiffV=0 powerDiffH=20.3
powerDiffV=0
```

Here ENIGMA measured a power difference of 20.3 dB. The next step is to set this value:

```
set  PowerDiffH 20.3
```

Now issue the **getadcdiff** command again.

```
getadcdiff
```

```
getadcdiff errormsg=null phaseDiffH=123.7 phaseDiffV=0
powerDiffH=0.013 powerDiffV=0
```

You see that the power difference now is effectively calibrated to 0 (with a very small residual error). Now you can calibrate the phase difference by issuing:

```
set  PhaseDiffH 123.7
```

Remark: Important is that you need to calibrate the power difference first, then measure again and calibrate the phase difference.

In case of a dual polarization system (with two extended dynamic channels) proceed in the same way for the vertical channel. This option is only available with the ENIGMA IFD+.

6.6 IF signal processing

6.6.1 Matched filter

The matched filter is implemented as FIR filter in the IFD. For coherent on receive radars (Magnetron, non coded pulse) the matched filter is a digital bandpass filter centered at the (folded if undersampling) IF frequency with a bandwidth corresponding to the pulse width:

Example:

- *IF frequency 60MHz*
- *Sampling frequency 76.8MHz (undersampling)*
- *1µs pulsewidth*

The bandpass filter should be centered at 16.8Mhz and have a bandwidth of 1MHz. The stopband attenuation should be as high as possible. Please refer to the 'Digital IF User Manual' for further details.

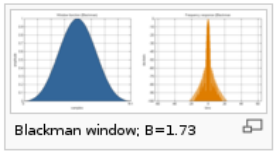
6.6.2 IFD matched filter

The batched filter for the IFD is a complex bandpass filter. The bandwidth of the passband has to be matched to the pulse width.

Example: For a pulse width of 1µs you will need a bandwidth of 1Mhz
For a pulse width of 2µs you will need a bandwidth of 500kHz

The matched filter is implemented as a complex (symmetric) FIR filter. The filter coefficients need to be symmetric and the the coefficients at both ends need to have values close to zero (causal filter). This can be achieved by applying a tapering window to the coefficients. The recommended tapering function is the blackman window.

Blackman window



$$w(n) = a_0 - a_1 \cos\left(\frac{2\pi n}{N-1}\right) + a_2 \cos\left(\frac{4\pi n}{N-1}\right)$$

$$a_0 = 0.42; \quad a_1 = 0.5; \quad a_2 = 0.08$$

Example code for the computation of the Blackman window:

```
double arg = 2.0*M_PI/(double)(size-1);
for (i=0; i<size; ++i)
{
  window[i] = 0.42-0.5*cos(arg*i)+0.08*cos(2.0*arg*i);
}
```

The recommended procedure for the computation of the filter coefficients is to first compute a real lowpass filter and then mix it up to the (folded) center frequency of the burst signal:

Example:

The sampling frequency of the ENIGMA III IFD is 76.8 MHz.

1. Assuming a IF frequency of 60 MHz the folded center frequency of the burst will be 16.8 MHz. So the low pass filter has to be mixed up to a center frequency of 16.8 MHz. In this case the IFD

performs undersampling of the IF signal. Please refer to common literature for further explanations about bandpass theory and band limited signals.

2. Assuming a IF frequency of 30 MHz the IF sampling frequency (76.8 MHz) fulfills the Nyquist criterion and there is no frequency folding. The lowpass filter needs to be mixed up to the IF frequency of 30 MHz.

6.6.3 Computation of a real lowpass filter

The are several methods for the computation of the filter coefficients like for example inverse FFT or the well known Remez algorithm. We recommend the Remez algorithm which is an iterative optimization algorithm for the computation of real FIR filter coefficients.

6.6.4 Mixing of the real lowpass filter to a linear phase complex bandpass filter

$$coeff_{bandpass}(x) = coeff_{lowpass}(x) * (\cos(2\pi \frac{f_{center}}{f_{sample}} x) + j \sin(2\pi \frac{f_{center}}{f_{sample}} x))$$

Example code for the mixing procedure:

```
centerFreq /= samplingFreq;

for (int i=0; i<numtap; ++i)
{
  Complex cFreq( cos( 2.0*M_PI*centerFreq*(i-numtap/2+0.5) ),
                 sin( 2.0*M_PI*centerFreq*(i-numtap/2+0.5) ));

  coeff[i] *= cFreq;
}
```

with

numtap	Number of coefficients
centerFreq	Center frequency (16.8MHz or 30MHz)
SamplingFreq	Sampling frequency (76.8MHz)
coeff[]	Lowpass filter coefficients

The number of coeffients must fulfill some constrains.

1. It must be a multiple of the given decimation factor. The decimation factor can be any number in the range [3...32].

2. This multiple of the decimation factor must be in the range [1...20]
3. The decimation factor limits the minimal range gating. As a rule of thumb: Smallest range gate possible is “decimation factor” * 2m. In other words. If you want a minimum range gating of 25 m the decimation factor must not be larger than 12 (which leads to 12*20=240 coefficients maximum which leads to a filter length in time of 3.125µs)

Example:

A filter with 200 coefficients can be created with:

1. decimation 10 (10*20=200)
2. decimation 20 (20*10=200)

A filter with 80 coefficients can for example be created with:

1. decimation factor 8 (8*10=80)
2. decimation factor 4 (4*20=80)
3. decimation factor 5 (5*16=80)
4. decimation factor 16 (16*5=80)

FIRCoeff0 – FIRCoeff3

FIR coefficients for pulse 0...3 respectively

Format: *FIRCoeffX <n> <C1I> <C1Q> <C2I> <C2Q> ... <CnI> <CnQ> <samplingFreq> <bandwidth> <transition> <centerFreq> <windowType> <alpha> <attenuation> <weight> <decimation> <dataRate> <scalingShiftFactor>*

n - Length of the FIR filter (number of complex coefficients)
CnI, CnQ - n'th I and Q filter coefficient.
samplingFreq - Sampling frequency in MHz (76.8 MHz)
bandwidth - Passband bandwidth in kHz (Used by Frog only)
transition - Passband transition in kHz (Used by Frog only)
centerFreq - center frequency in kHz (16800kHz for 60MHz IF and 30000kHz for 30MHz)
windowType - Window type (Used by Frog only)
alpha - Window alpha (Used by Frog only)

attenuation - Stopband attenuation in dB for Remez algorithm (used by Frog only)
weight - Weighting for Remez algorithm (used by Frog only)
decimation - Decimation factor (see remark)
dataRate - obsolete (set to 0)
scalingShiftFactor - obsolete (set to 1)

Remark: The values used by the Frog software only can be set to fixed values.

The number of coefficients must always be a multiple of the decimation factor. The decimation factor must be in the range [3...32] and the factor for the decimation must be in the range [1...20]

The filter coefficients will be uploaded to the signal processor by the burst configuration utility in FrogRT

6.6.5 Burst sampling

Burst sampling is controlled by the following parameters:

6.6.5.1 BurstTiming0 -BurstTiming3

Burst sample timing

Format: `BurstTimingX <burstCenterOffset> <afcSampleSize>`

burstCenterOffset - integer, default 0 (Sample count at sampling frequency)

afcSampleSize - unsigned, default 0 (Sample count at sampling frequency)

These parameters are best configured with the graphical utility (Burst configuration) in FrogRT

6.6.5.2 RangeAdjust0 – RangeAdjust3

Delay for sample start (Range step increments)

Type: **unsigned**
Default: **0**
Unit: **Range step increments**

Remark: *The timing for range=0 is configured with the* ***BurstTimingX****. The* ***RangeAdjust*** *parameter are intended for lowpass receiver with fixed range gating. These parameters should be set to 0.*

6.7 Video signal processing

Time series consist of an array of complex numbers

$s_n=I_n+jQ_n$

I and Q signals are sampled with configurable resolution. Standard is multiple of 25m but can be changed to any integer step in meteron user request.

Processing stages:

1) time averaging, clutter filtering, computation of autocorrelations
2) range sampling
3) weather moments computation and thresholding
4) distribution of weather moments

6.8 Autocorrelations.

SDP has three methods for calculation of filtered data and autocorrelations: Pulse-Pair (PPP), DFT and FFT processing.

6.8.1 AcfMode

This value specifies the used algorithm for the auto correlations.

Possible values:

0 – Pulse-pair
1 – DFT
2 – FFT

Type: **integer**
Default: **0**

6.9 Range

Specify the range as floating point value in km. Maximum range is 400km. It must be an interger multiple of the configured **RangeStep**.

Type: **float**
Default: **100.0**
Unit: **km**

6.9.1 RangeStep

Specify the range step as floating point value in km. The range step must be a multiple of the base resultion (25 m). Range stepping specifies the bin spacing for range sampling (see: RangeSample)

Type: **float**
Default: **0.125**
Unit: **km**

6.10 Range Sampling

The algorithm uses '**Range**', '**RangeStep**' and '**RangeSample**' parameters to average autocorrelations by range. This reduces the number of bins in the final data, improves the signal noise ratio and saves network traffic. During this step ClutterMicroSuppression is performed.

6.10.1 RangeSample

Specify the number of bins to be averaged (1-40). Example: If you specify a range step of 0.25km and range sample of 4 the final bin spacing will be 1km.

Type: **integer**
Default: **8**

NumBins = Range / (RangeStep*RangeSample)

Example:

- Range 100km
- RangeStep 50m
- RangeSample 10

The resulting bins have a resolution of 500m. The ray will contain 200 bins

6.10.2 Clutter Micro Suppression

Clutter micro suppression excludes bins from the range sampling step if the contained clutter power exceedes a configurable threshold (**ClutterMicroSuppressionThreshold**). The clutter power is estimated from the T_0 / R_0 ratio. Clutter micro suppression improves subclutter visibility when using the range sampling algorithm. Recommended values for the threshold are 30-40dB.

Type: **float**
Default: **0.0**
Unit: **dB**

6.11 ClutterFilter

Specify the clutter filter number. This value is used for Pulse Pair Processing , as well as for the FFT/DFT processing. Possible values depend on selected autocorrelation algorithm ('**AcfMode**' parameter), see corresponding 'Processing' sections. The larger the filter number is, the stronger filter is applied. 0 means 'no filter'.

Type: **integer**
Default: **1**

6.11.1 InterpolationMode

Clutter subtraction is performed in the frequency domain. It is possible to recognize the highly coherent echoes from the ground and cancel them in different ways. Cancellation method is chosen by this parameter.

Possible values are:

0 - DC Cancelation
1 - Half plane subtraction
2 – Interpolation
3 - Dual slope search interpolation

Type: **integer**
Default: **0**

6.11.2 FFTWindow

Possible values are:

0 – Rectangular
1 – Hamming
2 – Blackman
3 – Hann
4 – Welch
5 – Kaiser-Bessel

Type: **integer**
Default: **0**

6.11.3 ZeroFilter

Clear IIR filter for every ray

Type: **boolean**
Default: **false**

6.11.4 FilterDelay

Number of pulses to be discarded after filter zeroing (The recursive filter needs to be filled with data in order to stabilize)

Type: **integer**
Default: **0**

6.11.5 MaxFilterRange

The selected filter (which number is '**ClutterFilter**') is applied up to the specified range in km.

Type: **float**
Default: **100.0**
Unit: **km**

6.12 Measured offsets

6.12.1 IOffsetH

Inphase noise sampling average on horizontal channel. The value is subtracted from the 'I' data of the input time samples. It is calculated by noise sample procedure, stored in Frog-Muran software and set by it.

Type: **float**
Default: **0.0**

Remark: *The offsets are only used for lowpass receivers (video processing) as the A/D converter offset is effectively canceled by the matched bandpass filter.*

6.12.2 QOffsetH

Quadrature noise sampling average on horizontal channel. The value is subtracted from the 'Q' data of the input time samples. It is calculated by noise sample procedure, stored in Frog-Muran software and set by it.

Type: **float**
Default: **0.0**

Remark: *The offsets are only used for lowpass receivers (video processing) as the A/D converter offset is effectively canceled by the matched bandpass filter.*

6.12.3 IOffsetV

Inphase noise sampling average on vertical channel. The value is subtracted from the 'I' data of the input time samples. It is calculated by noise sampleprocedure, stored in Frog-Muran software and set by it.

Type: **float**
Default: **0.0**

Remark: *The offsets are only used for lowpass receivers (video processing) as the A/D converter offset is effectively canceled by the matched bandpass filter.*

6.12.4 QOffsetV

Quadrature noise sampling average on vertical channel. The value is subtracted from the 'Q' data of the input time samples. It is calculated by noise sample procedure, stored in Frog-Muran software and set by it.

Type: **float**
Default: **0.0**

Remark: *The offsets are only used for lowpass receivers (video processing) as the A/D converter offset is effectively canceled by the matched bandpass filter.*

6.13 PRFTable

Format of argument: staggering prf1 prf2 ... prf8

If staggering=0, only prf1 is used, otherwise dual PRF mode is used.

Eight PRF values are reserved for four pulse widths. PRF values are paired, every pair assigned for the corresponding pulse width. Higher and lower PRFs are determined automatically, order in the pair is not important. Default PRF is 600 for all pulse widths, no staggering.

Example:

```
set PRFTable=1 600 400 1200 800 300 200 600 400
```

6.13.1 PrfLimits

The duty cycle of the magnetron must not be exceeded. In case of an old radar which uses a now obsolete PFN the PRF must also not be too low, as this could damage the PFN.

Format of argument: 4x low PRF and 4x high PRF limits
Default: **250 250 250 250 400 400 400 400**

This parameter has to be set to ensure that the PRF (and the resulting duty cycle when switching PRF) is **hardware limited** by the signal processor.

Current pulse width is choosen by parameter **PulseWidthIndex**.

6.14 PulseWidthIndex

Index of the current pulse width. It is in range 0-3.

Type: **integer**
Default: **0**

6.15 NOISEThreshold

Positive value in dB.

Type: **float**
Default: **0.0**

Unit: **dB**

6.15.1 noisePowerH

Noise power on horizontal channel as measured by the noisesample command.

Type: **float**
Default: **0.0**

6.15.2 noisePowerV

Noise power on vertical channel asmeasured by the noisesample command.

Type: **float**
Default: **0.0**

6.16 dbz0

Horizontal/vertical calibration reflectivity for 4 pulse widths. **dBZ_0** is a calibration reflectivity, that is the minimum detectable dBZ at the reference range 1 km;

Calibration reflectivity table is in the 'dbz0' parameter.

Format of argument: <dbz0_pulse0_hor> <dbz0_pulse0_ver> ... <dbz0_pulse3_hor> <dbz0_pulse3_ver>

Default value: all array members are set to 0.0

6.17 RangeNorm

Range normalization algorithm switch.

20 log(r) is the range normalization, expressed in dB

Type: **boolean**
Default: **true**

6.18 gasAttenuation

Gaseous attenuation constant. **a*r** is the gaseous attenuation. 'r' is the range in km, 'a' is an attenuation factor. It can be set by parameter '`gasAttenuation`'. Parameter 'RangeNorm' enables/disables range correction.

Type: **float**
Default: **0.0**
Unit: **dB/km**

6.19 CCORThreshold

Negative value in dB for CCOR thresholding.

Type: **float**
Default: **-10.0**
Unit: **dB**

6.20 SQIThreshold

Positive value in the range [0,1]

Type: **float**
Default: **0.0**

6.21 Rain attenuation correction

$\mathbf{A_R}$ is the rain attenuation correction. The value depends on the previous bin value.

$$A_{Rn} = a \cdot A^{-\frac{b}{B}} \cdot \Delta r \cdot 10^{\frac{Z_{n-1} \cdot b}{10 \cdot B}}$$

a, b, A, B are constants stored in parameters RainAttenuation_a, RainAttenuation_b, RainAttenuation_A, RainAttenuation_B.

Δr is the range step.

Z_{n-1} is a reflectivity for the previous bin, that is sampled from the same ray on the smaller range.

6.21.1 RainAttenuation

This parameter switches on/off rain attenuation correction";

Type: **boolean**

Default: **false**

6.21.2 RainAttenuation_a

Parameter 'a' of the rain attenuation correction formula.

Type: **float**
Default: **0.0044**

6.21.3 RainAttenuation_b

Parameter 'b' of the rain attenuation correction formula.

Type: **float**
Default: **1.17**

6.21.4 RainAttenuation_A

Parameter 'A of the rain attenuation correction formula.

Type: **float**
Default: **200.0**

6.21.5 RainAttenuation_B

Parameter 'B' of the rain attenuation correction formula.

Type: **float**
Default: **1.6**

6.22 Threshold algorithms.

Enigma III generates the following moments:

- Reflectivity Z
- Velocity V
- Spectrum width W
- Uncorrected reflectivity U

There are four threshold checking algorithms in Enigma III:

- CCOR
- SQI
- RHOHV
- NOISE

These algorithms can be combined using boolean functions AND and OR. Internally, Enigma III checks above thresholds and creates a value that describes the results.

- If calculated CCOR less or equal then CCOR threshold, bit 0 is set.
- If calculated SQI less or equal then SQI threshold, bit 1 is set.
- If calculated RHOHV less or equal then RHOHV threshold, bit 2 is set.
- If calculated SNR greater or equal then NOISE threshold, bit 3 is set.

This value is an index in range 0-15 in the 'pass table'. The unsigned 16 bit word from the table is a set of bits. If some bit is set, the appropriate moment is passed, otherwise is thresholded. There is a relation between bit number in the word and moment:

- Z - bit 0
- V - bit 1
- W - bit 2
- U - bit 3

Other bits are reserved for dual polarization moments.

The threshold table is stored in the parameter '**thresholdFlagsTable**'.

6.22.1 thresholdFlagsTable

Format of the argument: "word0 word1 .. word15".

Type: **Every word is a 16 bit unsigned decimal.**
Default: **65535** in every word (means 'All pass')

Remark: *Use the* ***EnigmaThresholdFlagCalculator*** *tool to obtain the bit values*

6.22.2 Speckle removal

Speckle filter removes isolated bins in the ray. Filters are enabled separetaly for reflectivety Z and velocity V by the following parameters:

6.22.2.1 SpeckleRemoverZ

Enable/disable speckle remover for Z/UZ data

Type: **boolean**
Default: **false**

6.22.2.2 SpeckleRemoverV

Enable/disable speckle remover for velocity data.

Type: **boolean**
Default: **false**

7 Acquisition

The following moments can be extracted from the radar data.

7.1 Spectrum Width.

The spectrum width is normalized to the Nyquist interval [-1;1] and calculated by formula:

$$W = \frac{\sqrt{\frac{2}{3}\ln\left(\frac{|R_1|}{|R_2|}\right)}}{\pi}$$

W is multiplied by the unfolding factor on the low PRF in dual PRF mode .

Unfolding factor =PRF_{Low} / PRF_{High} .

The unfolding factor is calculated from the PRF table. It is set by '**PRFTable**' parameter.

7.2 Reflectivity.

The corrected reflectivity is calculated by the formula:

$$Z = SNR + dBZ_0 + 20 \cdot \log(r) + a \cdot r + CCOR + A_R$$

where:

SNR is a signal-to-noise ratio, calculated by the formula:

$$SNR = 10 \cdot \log\left(\frac{T_0 - N}{N}\right) \quad ;$$

T_0 is calculated in the autocorrelation algorithm.

The noise power N is calculated in the noise sampling procedure or in the adaptive noise sampling algorithm. N of the noise sampling is stored in the following parameter:

SNR value is compared with the parameter '**NOISEThreshold**' to eliminate values below the threshold.

7.3 Signal quality index (SQI)

SQI is a normalized magnitude of the first lag of autocorrelation.

$$SQI = \frac{|R1|}{R0}$$

It is in the range of [0;1]. 0 is a white noise, 1 is a perfectly-correlated signal.

SQI value is compared with the parameter 'SQIThreshold' to eliminate values below the threshold.

7.4 CCOR clutter correction

$$CCOR = 10 \cdot \log\left(\frac{S}{S + T_0 - R_0}\right)$$

$$S = |R_1| \exp\left(\frac{\pi^2 \cdot W^2}{2}\right)$$

This value is compared with the parameter 'CCORThreshold' to eliminate values below the threshold.

7.5 Radial Velocity

Doppler velocity is calculated from the autocorrelation R_1 by formula:

$$V = \frac{arg(R_1)}{\pi}$$

It is normalized to the Nyquist interval [-1;1].

Phase unfolding is performed in dual-PRF mode using PRFs ratio.Supported values are 2:3, 3:4 and 4:5.

7.6 Acquisition parameter

Acquired data are available over the separate TCP connection. SDP listens on the port 5556 for incoming connection. Only one is established at the time.

Some parameters configure the transmission of the acquired data.

7.6.1 RaySize

Expected by client ray size in bytes. This is for the FrogRadar compatibility. If expected raysize equals to 0, it is not taken into account. SDP shrinks or grows the amount of bytes in the ray to this value. Additional bins filled with 'thresholded' value.

Type: **integer**
Default: **0**

Related parameter: **LongRaySize**

7.6.2 LongRaySize

If this parameter is set to true, the raysize word in the ray header will be 32bit instead of 16bit. It is recommended to set this parameer to true if you want to work with 16bit moments and large amounts of bins.

Type: boolean
Default: false

7.6.3 SyncModeParam

Argument format: <mode> <angle_step> <pulses>

<mode> - Syncing modes may be:

0 - Timesampling
1 - Azimuth Dynamic Angle Syncing
2 - Elevation Dynamic Angle Syncing

<angle_step> angle step in dynamic angle syncing mode. It is in decimal degrees, floating point
<pulses> is the number of pulses for averaging in timesampling mode.

7.7 AFCSettings

Parameters: staloID staloMinTuneRFFreq staloMinTuneUnit staloMaxTuneRFFreq staloMaxTuneUnit afcCoarseFreqStep afcFineFreqStep afcTuneBandwidth afcBurstIFFreq afcFreqThresh afcBurstPowerThresh afcLoopSettingTime afcStaloNominalFreq flags

staloID - uint
staloMinTuneRFFreq - float in MHz
staloMinTuneUnit - float in V
staloMaxTuneRFFreq - float in MHz
staloMaxTuneUnit - float in V
afcCoarseFreqStep - float in kHz
afcFineFreqStep - float in kHz
afcTuneBandwidth - float in MHz
afcBurstIFFreq - float in MHz
afcFreqThresh - float in kHz
afcBurstPowerThresh - floa in dBt
afcLoopSettingTime - float in ms
afcStaloNominalFreq - float in MHz
flags - uint, bits with following masks control the settings

0x0001 - Negative AFC Tuning Slope
0x0002 - Invert IQ
0x0100 - AFC
0x0200 - MFC
0x0400 - MFC Hold
0x0800 - AFC Search
0x1000 - Set Mode Only

7.8 DualPolMode

If true, dual polarization mode is used, otherwise single polarization mode. Ray format depends on the parameter.

Type: **boolean**
Default: **false**

7.9 Dual polarization specific parameter

When used in dual polarization mode the ENIGMA signal processor will use the following cammands in addition to the standard commands.

7.9.1 ZdrOffset

The bias in the horizontal/vertical receiver path needs to be calibrated in order to get a ZDR reading of zero for the first range gate. The corresponding parameter is **ZDROffset**.

Type: **float**
Default: **0**
Unit: **dB**

7.9.2 LdrOffset

The bias in the horizontal/vertical receiver path needs to be calibrated in order to get a LDR reading of zero for the first range gate. The corresponding parameter is L**DROffset**.

Type: **float**
Default: **0**
Unit: **dB**

7.9.3 PhidpOffset

The constant phase difference between the horizontal/vertical receiver channel needs to be calibrated in order to get a PhiDP reading of zero for the first range gate. The corresponding parameter is **PhidpOffset**.

Type: **float**
Default: **0**
Unit: **degree**

7.9.4 RHOHVThreshold

In dual polarization mode the RhoHV (cross correlation between horizontal and vertical channel) coefficient can be used as threshold parameter. The threshold flags need to be set accordingly.

Type: **float**
Default: **0**

7.10 DataFormat

Output data format type. Ray format depends on the parameter. In single pol mode:

- 0 - Angle Data
- 1 - Moments 8 bit

- 2 - Log,I,Q 8 bit
- 3 - I,Q 16 bit
- 4 - SQI/CCOR 8 bit
- 5 - Power spectrum
- 6 - Moments 16 bit
- 7 - Full moments 16 bit

In dual pol mode:

- 0 – Angle data
- 1 – Moments 8 bit
- 2 – Log,I,Q 8 bit
- 3 – I,Q 16 bit
- 4 – SQI/CCOR 8 bit
- 5 – Power spectrum
- 6 – Horizontal LDR mode moments 8 bit
- 7 – Moments 16 bit
- 8 – Horizontal LDR mode moments 16 bit
- 9 – Full Moments 16 bit
- 10 – Full Horizontal LDR moments 16 bit

Type: **integer**
Default: **1**

Acquisition is started and stopped by corresponding commands '**startacq**' and '**stopacq**'. They don't have arguments and return values.

7.11 Ray format

Ray consists from:

- ray header
- ray bins

Ray header has the same format for all modes.

Then 'N' ray bins follow. Amount of bins is calculated by the formula:

N=Range/(RangeStep*RangeSample)

Format of the bin depends on the '**DataFormat**' and '**DualPolMode**' parameters.

7.11.1 Ray header format.

All values have network byte order.

Field	Description	Length in bytes	Unit
Ray size	Size of the whole ray in bytes, 16 bit unsigned value (or 32 bit unsigned value if **LongRaySize** is true)	2 (4)	
Burst power	Burst power, 32 bit unsigned value	4	m dB
Burst frequency	Burst frequency, 32 bit unsigned value	4	Hz
Timestamp	Timestamp of the ray, 64 bit unsigned value	8	µs (relative)
Operational mode	16 bit value, always 0, reserved for future use	2	
SDP flags	Six 16 bit flags	12	
SDP status	Fourteen bytes	14	
Azimuth speed in °/s	16 bit value (same coding as elevation TAGS)	2	°/s
Elevation speed in °/s	16 bit value (same coding as elevation TAGS)	2	°/s
Azimuth start	Azimuth TAG, 16 bit resolution	2	°
Elevation start	Elevation TAG, 16 bit resolution	2	°
Azimuth stop	Azimuth TAG, 16 bit resolution	2	°
Elevation stop	Elevation TAG, 16 bit resolution	2	°

7.11.1.1 SDPFlags

WORD 0:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
								AM0	AM1	AM2	PWR	FIFO	UL	DL	AFC

AFC 1 if AFC locked
DL 1 if IFD downlink ok
UL 1 if IFD uplink ok
FIFO 1 if PCI-Receiver card FIFO ok
PWR 1 if IFD power supply ok
AM0-AM2 3 bit encoding the AFC mode
0 – AFC
1 – MFC
2 – AFC Search
3 – MFC Hold
4 – AFC Hold

Words 1-5 are reserved

7.11.1.2 SDPStatus

Byte 0: ENIGMA host CPU usage in %
Byte 1: ENIGMA host amount of free memory in %
Byte 2: ENIGMA host CPU temperature in °C
Byte 3: Sync pulse count (add 1 for actual value)
Byte 4: IFD ambient temperature in °C
Byte 5: IFD core temperature in °C
Byte 6: Burst channel ambient temperature int °C (A value of -128 means **not available**)
Byte 7: Horizontal channel ambient temperature in °C (A value of -128 means **not available**)
Byte 8: Vertical channel ambient temperaturein °C (A value of -128 means **not available**)

Bytes 9-13 are reserver for future use.

A simple formula to convert binary TAG values into ° would be:

unsigned degree = (unsigned)TAG * 359.9945068359375 / 65535
signed degree = (signed)TAG * 179.9945068359375 / 32767

7.11.2 Angle Data

No bins are sent, only ray header

7.11.3 Moments

In single polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold
Z	[-32;95.5] dBZ	1	Yes
V	[-1;1]	1	Yes
U	[-32;95.5] dBZ	1	Yes
W	[0;1]	1	Yes

In dual polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold
ZH	[-32;95.5] dBZ	1	Yes
VH	[-1;1]	1	Yes
UH	[-32;95.5] dBZ	1	Yes
WH	[0;1]	1	Yes
ZV	[-32;95.5] dBZ	1	Yes
VV	[-1;1]	1	Yes
UV	[-32;95.5] dBZ	1	Yes
WV	[0;1]	1	Yes
PHIDP	[-180;180] °	2	Yes
ZDR	[-6.5;6.5] dB	1	Yes
KDP	[-15;15] °/km	1	Yes
RHOHV	[0;1]	1	Yes

V and W must be multiplied to the maximum unambiguous velocity after the conversion to the specified range.

7.11.4 Mag,I,Q 8 bit

In single polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold
I	[-32767,32768] ADU	1	No
Q	[-32767,32768] ADU	1	No
MAG	[0, 32768] ADU	1	No
dummy	n/a	1	No

In dual polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold
IH	[-32767,32768] ADU	1	No
QH	[-32767,32768] ADU	1	No
MAGH	[0, 32768] ADU	1	No
IV	[-32767,32768] ADU	1	No
QV	[-32767,32768] ADU	1	No
MAGV	[0, 32768] ADU	1	No

7.11.5 I,Q 16 bit

In single polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold
I	[-32767,32768] ADU	2	No
Q	[-32767,32768] ADU	2	No

In dual polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold
IH	[-32767,32768] ADU	2	No
QH	[-32767,32768] ADU	2	No
IV	[-32767,32768] ADU	2	No
QV	[-32767,32768] ADU	2	No

7.11.6 SQI/CCOR 8 bit

In single polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold

SQI	[0,1]	1	No
CCOR	[-90,0] dB	1	No

In dual polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold
SQIH	[0,1]	1	No
CCORH	[-90,0] dB	1	No
SQIV	[0,1]	1	No
CCORV	[-90,0] dB	1	No

7.11.7 Power spectrum

Amount of bins in this mode equals to number of pulses to sample, stored int 'SyncModeParam'.

The DC component is in the middle of bin series.

bin = 100*(10*log(linpower)-carrier), where carrier = 10 * log(32768*32768*2) is an offset

Bin value is encoded in 16 bits, network byte order. In dual polarization mode two values per bin are sent, for horizontal and vertical polarisation.

Remark: *Power spectrum is calculated on the selected range.*

7.11.8 Horizontal LDR mode moments 8 bit

LDR moments are available only in dual polarization mode:

Moment	Mapped range of values	Size in bytes	Threshold
Z	[-32;95.5] dBZ	1	Yes
V	[-1;1]	1	Yes
U	[-32;95.5] dBZ	1	Yes
W	[0;1]	1	Yes
LDR	[-63.75;0] dBZ	1	Yes

7.11.9 Moments 16 bit

In single polarization mode

Moment	Mapped range of values	Size in bytes	Threshold
Z	[-64;128] dBZ	2	Yes
V	[-1;1]	2	Yes
U	[-64;128] dBZ	2	Yes
W	[0;1]	2	Yes

In dual polarization mode

Moment	Mapped range of values	Size in bytes	Threshold
ZH	[-64;128] dBZ	2	Yes
VH	[-1;1]	2	Yes
UH	[-64;128] dBZ	2	Yes
WH	[0;1]	2	Yes
ZV	[-64;128] dBZ	2	Yes
VV	[-1;1]	2	Yes
UV	[-64;128] dBZ	2	Yes
WV	[0;1]	2	Yes
PHIDP	[-180;180] °	2	Yes
ZDR	[-32;32] dB	2	Yes
KDP	[-20;20] °/km	2	Yes
RHOHV	[0;1]	2	No

7.11.10 Full Moments 16 bit

In single polarization mode

Moment	Mapped range of values	Size in bytes	Threshold
Z	[-64;128] dBZ	2	Yes
V	[-1;1]	2	Yes
U	[-64;128] dBZ	2	Yes
W	[0;1]	2	Yes

SQI	[0,1]	2	No
CCOR	[-90,0] dB	2	No
SNR	[0,250] dB	2	No

In dual polarization mode

Moment	**Mapped range of values**	**Size in bytes**	**Threshold**
ZH	[-64;128] dBZ	2	Yes
VH	[-1;1]	2	Yes
UH	[-64;128] dBZ	2	Yes
WH	[0;1]	2	Yes
ZV	[-64;128] dBZ	2	Yes
VV	[-1;1]	2	Yes
UV	[-64;128] dBZ	2	Yes
WV	[0;1]	2	Yes
PHIDP	[-180;180] °	2	Yes
ZDR	[-32;32] dB	2	Yes
KDP	[-20;20] °/km	2	Yes
RHOHV	[0;1]	2	No
SQIH	[0,1]	2	No
CCORH	[-90,0] dB	2	No
SNRH	[0,259] dB	2	No
SQIV	[0,1]	2	No
CCORV	[-90,0] dB	2	No
SNRV	[0,250] dB	2	No

7.11.11 Horizontal LDR moments 16 bit

Moment	**Mapped range of values**	**Size in bytes**	**Threshold**
Z	[-64;128] dBZ	2	Yes

V	[-1;1]	2	Yes
U	[-64;128] dBZ	2	Yes
W	[0;1]	2	Yes
LDR	[-64;0] dB	2	Yes

7.11.12 Full Horizontal LDR moments 16 bit

Moment	Mapped range of values	Size in bytes	Threshold
Z	[-64;128] dBZ	2	Yes
V	[-1;1]	2	Yes
U	[-64;128] dBZ	2	Yes
W	[0;1]	2	Yes
LDR	[-64;0] dB	2	Yes
SQI	[0,1]	2	No
CCOR	[-90,0] dB	2	No
SNR	[0,250] dB	2	No

8 Commands

Most of the commands can only be performed when the data acquisition is stopped (See commands **stopacq** and **startacq**). Keep in mind that this will corrupt any running schedulers as the direct command interface bypasses the scheduler and the running Frog software. When operating the ENIGMA signalprocessor with the Frog/MURAN software it is virtually never necessary to perform any of these commands manually.

8.1 Noise sampling

Noise sampling is performed by command 'noisesample'.

Parameters:

startRange - in km

prf - in Hz

It returns the following values:

IoffsetH=<val> - Offset of horizontal I

IoffsetV=<val> - Offset of vertical I

QoffsetH=<val> - Offset of horizontal Q

QoffsetV=<val> - Offset of vertical Q

noisePowerH=<val> - Horizontal noise power

noisePowerV=<val> - Vertical noise power

8.2 SDP status

In addition to the ray header, some status is obtained by the following commands:

8.2.1 getburst

get burst parameters. Returns:

sigpow - signal power in dB

freq - burst freq in Hz

phase - burst phase in degree

8.2.2 getantennaspeed

get antenna params. Returns:

azspeed azimuth speed, deg/s

elspeed elevation speed, deg/s

8.2.3 gettemperature

Temperature in degrees, zero means not available. Output arguments:

ambientIFDigPart - ambient temperature, IF Digitizer Digital part, degree

coreIFDigPLD - core temperature, IF Digitizer PLD, degree

ambientIFDigBurst - ambient temperature, IF Digitizer ADC Burst Channel, degree

ambientIFDigHor - ambient temperature, IF Digitizer ADC Horizontal Channel, degree

ambientIFDigVer - ambient temperature, IF Digitizer ADC Vertical Channel, degree

These values are also found in the ray header.

8.2.4 getpower

Power status. Output arguments:

plus5dig - IF Digitizer Digital Power Supply +5Volt status, boolean

minus5dig - IF Digitizer Digital Power Supply -5Volt status, boolean

plus15dig - IF Digitizer Digital Power Supply +15Volt status, boolean

minus15dig - IF Digitizer Digital Power Supply -15Volt status, boolean

plus3d3dig - IF Digitizer Digital Power Supply +3.3Volt status, boolean

plus3d3an - IF Digitizer Analog Power Supply +3.3Volt status, boolean

plus5an - IF Digitizer Analog Power Supply +5Volt status, boolean

minus5an - IF Digitizer Analog Power Supply -5Volt status, boolean

8.2.5 getconverter

Converter status. Output arguments:

BurstOverflow - ADC Burst Channel Converter Overflow status, boolean

HorOverflow - ADC Horizontal Channel Converter Overflow status, boolean

VerOverflow - ADC Vertical Channel Converter Overflow status, boolean

BurstConfig - ADC Burst Channel Converter Configuration: 0-not used, 1-14 bit converter, 2-16 bit converter

HorConfig - ADC Horizontal Channel Converter Configuration: 0-not used, 1-14 bit converter, 2-16 bit converter

VerConfig - ADC Vertical Channel Converter Configuration: 0-not used, 1-14 bit converter, 2-16 bit converter

8.2.6 getacqperformance

Get acquisition perfomance. Output argument:

PulseProRay - pulses per ray

8.2.7 getafcstatus

Get AFC status. Output argument:

freqMFC - STALO MFC RF frequency, Hz, float

meanBurstIFFreq - Mean Burst IF frequency, HZ, float

meanBurstIFPower - Mean Burst IF power, dB, float

afcMode - AFC Mode, unsigned 32 bit
0 – AFC
1 – MFC
2 – AFC Search
3 – MFC Hold
4 – AFC Hold

afcLock - AFC Lock, unsigned 32 bit
0 – Unlocked
1 - Locked

8.3 getversion

Returns version numbers of hardware protocol and firmware versions for DSP and FPGAs. Output:

protocol - HW communication protocol, unsigned

dsp - PCI DSP firmware version,unsigned

fpgaPci - PCI FPGA firmware version, unsigned

fpgaIfd - IFD FPGA firmware version, unsigned

software - ENIGMA software version, unsigned

8.4 sampleburst

Get burst samples centeredaround t=0. This command is used by the burst confguration tool in FrogRT

Parameter: SamplesNum, integer

Returns: SamplesData – array of , specified number of burst samples

8.5 setafcmode

Parameter: mode
0 – AFC
1 – MFC
2 – AFC Search
3 – MFC Hold
4 – AFC Hold

staloMFC_RFFreq (Frequency in Hz)

8.6 getifsampling

Request IF sampling parameters

Parameter: None

Returns:

IFFreq	(IF frequency)
maxFilterDecFactor	(maximum filter decimation factor)
maxFilterNumberMult	(maximum filter multiplication factor)
minDataRateFactor	(minimum data rate)

8.7 settxdtrigger

Enable/disable transmitter trigger

Parameter: 0 – Disable trigger, 1- Enable trigger

8.8 geterrorconditions

Get the internal errors from the PCI-Receiver card. The command resets all errors.

Parameter: None

Returns: Space separated list of error codes

1 - Error: PCI external FIFO full
2 - Error: Fiber downlink laser detection
3 - Error: Fiber downlink synchronization loss
4 - Error: PCI internal FIFO full
5 - Error: Downlink data header word 0
6 - Error: Downlink data header word 15
7 - Error: PCI pass through
8 - Error: PCI pass through unknown command
9 - Error: Filter coefficients command
10 - Error: PCI External FIFO Full
11 - Error: Uplink

128 - Warning: PCI external FIFO almost full
129 - Warning: Unambiguous range number of bins
130 - Warning: Filter coefficients command
131 - Warning: PRF command";

8.9 build

Returns the 'buildstring' of the ENIGMA host firmware.

Example: **`build errormsg=null version=1.3.16 SIAMCC_LINUX26`**

Host software version is 1.3.16 and was compiled for kernel 2.6.x

8.10 load

Load parameter from previously stored configuration file. The configuration files are located in `/opt/enigma3.` The filename is `controlagent_X.is` (with X corresponding to **SDPType**)

8.11 save

Save parameter to configuration file. The configuration files are located in `/opt/enigma3`. The parameter are stored in the file `controlagent_X.is` (with X corresponding to **SDPType**)

8.12 quit

End the current telnet session.

9 Specifications

9.1 Mechanical specification

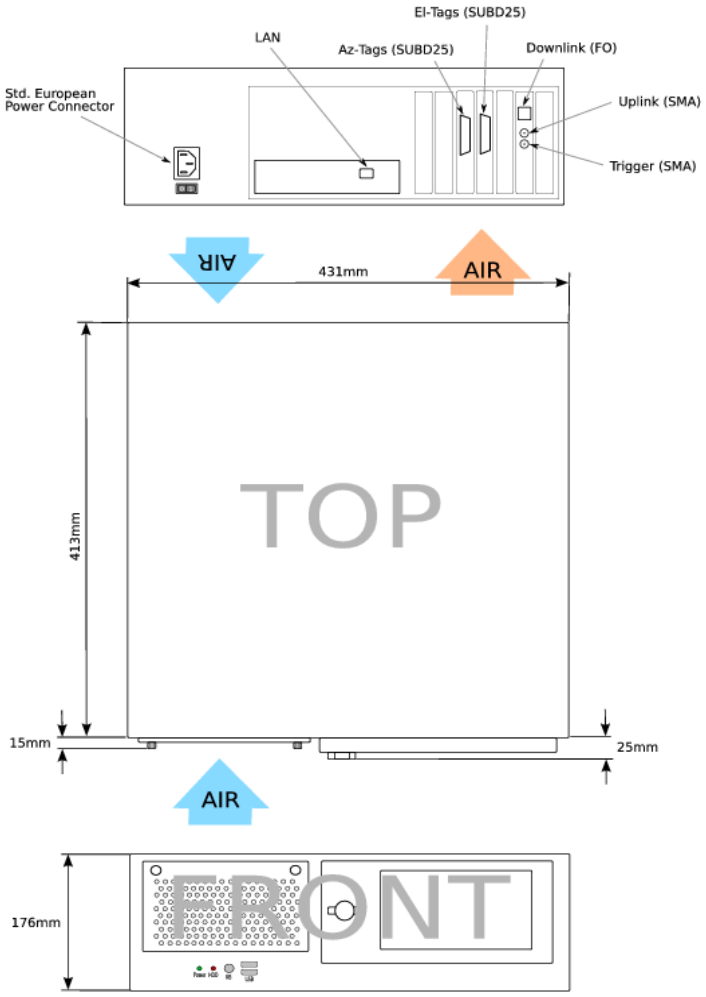


Illustration 27: ENIGMA III 19" enclosure

9.2 Electrical specification

9.2.1 Input voltage

220-240 Volt AC, 50-60 Hz,
Measured Power consumption : 110 Watt
Expected maximum Power consumption : 200 Watt

9.2.2 Input Downlink

Connector Type : Simplex Fibre, female

9.2.3 Output Uplink

Connector Type : SMA, female

9.2.4 Output Trigger

Connector Type : SMA, female
5 Volt buffered 50 Ohm

9.2.5 Input Azimuth TAG parallel

Connector Type: 25 SUBD, female, 16 bit TTL

PIN 1: AZ0 (LSB)
PIN 2: AZ1
PIN 3: AZ2
PIN 4: AZ3
PIN 5: AZ4
PIN 6: AZ5
PIN 7: AZ6
PIN 8: AZ7
PIN 9: AZ8
PIN 10: AZ9
PIN 11: AZ10
PIN 12: AZ11
PIN 13: AZ12
PIN 14: AZ13
PIN 15: AZ14
PIN 16: AZ15 (MSB = 180 degree)

PIN 23: GND
PIN 24: GND
PIN 25: GND

9.2.6 Input Elevation TAG parallel

Connector Type: 25 SUBD, female, 16 bit TTL

PIN 1: EL0 (LSB)
PIN 2: EL1
PIN 3: EL2
PIN 4: EL3
PIN 5: EL4
PIN 6: EL5
PIN 7: EL6
PIN 8: EL7
PIN 9: EL8
PIN 10: EL9
PIN 11: EL10
PIN 12: EL11
PIN 13: EL12
PIN 14: EL13
PIN 15: EL14
PIN 16: EL15 (MSB = 180 degree)

PIN 23: GND
PIN 24: GND
PIN 25: GND

9.2.7 Input TAGS serial RS422

Connector Type: 9 SUBD female, RS 422

PIN 3: Rx +
PIN 5: GND
PIN 8: Rx -

The remaining pins are not connected. The baudrate is freely programmable up to 2Mbit/s.

9.3 Environmental requirements

Ambient temperature : 4 - 40 Degree C

Relative humidity : 10 – 90 %

Technical specification - Single Polarization

9.3.1 ENIGMA III IF DIGITIZER (IFD)

IF Receiver inputs	3 channel, horizontal, vertical and reference
IF frequency	30 MHz or 60 MHz (other frequencies optional)
IF Dynamic range	> 100 dB (2 us pulse width)
ADC Sampling frequency	76.8 MHz, 16 bit resolution
AFC	Analog output: maximum span for +/- 10 Volt Digital output: 16 bit parallel format, 3 wire serial format or RS232 format
Matched Filter	- Complex Digital Decimating Bandpass Filter, matched t - Transmitter Pulsewidth - Filter Coefficients configurable via uplink connection - FIR (Finite Impulse Filter) Implementation - Robust FPGA Implementation for maximum performance - Performance 12.3 GOPS (Giga Operations per Second) - Dual Polarization ready - Single Fiber Downlink Connection for dual polarization mode
Range base resolution	125 m, 100 m, 50 m or 25 m
Connectors	- Coaxial high speed serial uplink (isolated) - Fiber optic 1.2 GBits/s downlink - Serial debug interface (RS-232) - Two general purpose trigger outputs - Two coherent general purpose analog ouputs - 16 Bit general purpose 5V digital I/O
Power Supply	Separate shielded linear regulated power supply for optimum performance
Power consumption	< 25W, 230 V AC, 50 Hz
Digitizer enclosure	Precision milled aluminum case for optimum EM shielding

9.3.2 ENIGMA III Host

Number of bins	4096
Typical base resolution	125m
Range	10-400km
PRF	10-3000 Hz
Number of Pulse widths	4 with independent configurable matched filters (up to 1280 taps)
Dual PRF Stagger Modes	None, 2/3, 3/4 and 4/5
Output data	- Corrected reflectivity Z - Uncorrected reflectivity UZ - Radial velocity V - Spectral Width W - Clutter power CCOR - Signal quality index SQI - Inphase/Quadrature signal I, Q - Power spectrum DFT
Processing Modes	- Pulse Pair Processing (PPP) - FFT Processing (FFT) - DFT Processing (DFT)
PPP	- Selectable 40dB and 50dB IIR filter coefficients - Filter width adjustable in 8 steps (Allpass, Filter 1-7) - Range adjustable 1-400km - Filter zeroing on/off - Configurable filter stabilization delay' - Clutter micro suppression

FFT and DFT	- Adaptive filter width adjustable in 8 steps (Allpass, Filter 1-7)
	- Range adjustable 1-400km
	- Clutter micro suppression
	- Selectable interpolation:
	  - DC cancelation
	  - Half plane subtraction
	  - Interpolation
	  - Dual slope interpolation
	- Selectable tapering window
	  - Rectangle
	  - Hamming
	  - Blackman
	  - Hann
	  - Welch
	  - Kaiser-Bessel

Time averaging	Adjustable time samples (8-256) or Dynamic angle syncing (0.1°-5°)
Data quality algorithms	- Rain attenuation correction - $1/r^2$ range normalization - Gas attenuation correction - Reflectivity speckle remover (2 Dimensional) - Velocity speckle remover - Configurable thresholding with NOISE, CCOR and SQI
I/Q Recorder	Pulse wise I/Q recording in 32Bit IEEE floating point format to the internal harddisk
Configuration	FROG/MURAN Network capable GUI, telnet or through the built in HTTP server (comprehensive browserinterface).
Matched filter designer	GUI program for semi automatic calculation of matched filter coefficients (for transmitter pulse) and verification. Comprehensive AFC configuration and visualization.

Status information	- Host CPU load, CPU temperature and amount of free memory - Host Voltages - IFD power supply - IFD temperatures - A/D converter status - AFC Status - Number of pulses for autocorrelation
PCI receiver card	Standard PCI card. - Buffered 5V, 50Ohm trigger output - Parallell standard angle TAG input (Azimuth and Elevation) - Optional: Serial (3 wire) angle TAG input - Coaxial high speed serial uplink (isolated) - Fiber optic 1.2 GBits/s downlink
Host enclosure	Standard 19" rack mount (3 or 4 HE). Depth 420mm or custom enclosure.
Host boot media	Robust flash disk for antenna mount receiveror single Harddisk drive. Optional: RAID 0 for I/Q recorder (Rack mount only)
Host Power consumption	< 200 W, 230 V, 50 Hz

10 Maintenance and firmware update

10.1 Enigma III host update

To upgrade DSP programs do following:

1. Type "`/etc/init.d/muran stop`" to stop the running Frog Muran system.
2. Type "`ssh root@enigma3 /etc/init.d/enigma3 stop`" to login into ENIGMA signalprocessor
3. Enter password when prompted"

   WARNING: Enigma software MUST be stopped before upgrading the firmware
4. Type "`cat newfile.tgz | ssh root@enigma3 tar -xzvp -C /`" to install the new version of enigma firmware.
5. run the command "`ssh root@enigma3 /etc/init.d/enigma3http start`" to restart the DSP after firmware update.

10.2 PCI-Receiver card update

To upgrade PCI-Receiver card do the following:

1. Stop the Frog/Muran software on the radar computer. Open a shell and type "`/etc/init.d/muran stop`" to stop the running Frog Muran system.
2. Type "`ssh root@enigma3`" to login into enigma3 DSP
3. Enter password when prompted.The preconfigured password is "`gamic`"
4. stop the signal processor by typing "`/etc/init.d/enigma3 stop`"
   WARNING: *Enigma software MUST be stopped before upgrading the firmware*
5. Copy the file containing the firmware to the ENIGMA computer and run the command "`flashenigma3dsp filename.hex`" where *filename* is the filename of the file for the upgrade
6. If you are physically close to the ENIGMA host computer (eg. you can hear the audi confirmation) wait for the audio confirmation from the PCI-receiver card, otherwise wait for 30 seconds.
7. run the command "`/etc/init.d/enigma3http start`" to restart the DSP after firmware update.

8. Start the Frog/Muran system on the radar computer by calling "`/etc/init.d/muran start`"

10.3 Antenna alignment

As part of the installation of a radar system, the antenna has to be leveled and aligned to true north. Usually this is done mechanically. The ENIGMA III signalprocessor has the ability to correct the azimuth and elevation TAGS. The parameter **AzimuthAbsoluteOffset** and **ElevationAbsoluteOffset** are used for this. The configured angles will be added to the TAGS before any processing. Commands sent to the RCC also need to be corrected. The Frog/MURAN software can either handle the offsets by software or send the appropriate commands to the RCC.

AzimuthAbsoluteOffset: calibration offset for antenna alignment

ElevationAbsoluteOffset: calibration offset for antenna alignment

Some systems work with separate synchro encoders to provide the TAGS. These can be calibrated with the following two parameters.

AzimuthSynchroOffset: calibration offset for encoder/synchro difference

ElevationSynchroOffset: calibration offset for encoder/synchro difference

10.4 Setting prf limits

1. In signal processor Enigma PRF limits are set by following:

2. Open a console in a Frog host

3. type "*`telnet enigma3 5555`*"

4. type "*`auth Secondary`*"

5. type "*`set PrfLimits lowprf0 lowprf1 lowprf2 lowprf3 highprf0 highprf1 highprf2 highprf3`*" where lowprf and highprf are the minimum and maximum prf values.

10.5 IQ Recording

Recording of the I/Q-data of the PCI-receiver-board in full resolution in configurable ring-buffer on the signal-processing PC

Open a console and type:

- `telnet enigma3 5555`
- `auth Secondary`
- `set RecordName 'filename'`
- `set RecorderMode 1`

Remark: *filename is the user given filename for the recorded data. The command "set RecorderMode 1" starts the recording.*

Remark: *The recording is stopped when ENIGMA receives a **stopacq** command. When still in RecorderMode 1 it will start the recording again with an empty file when receiving a **startacq** command.*

- wait a while for recording to take place
- to stop recording, type in the console:
  `set RecorderMode 0`

to close the telnet connection type

`ctrl + ]`

To get the recorded data type in a console:

`ssh root@enigma3`

enter password when prompted

type

`cd /data`

`ls`

The recorded data with the user given filename will be shown.